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PROFESSIONAL PAPERS OF THE CORPS OF ENGINEERS. U. S. ARMY
No. 29

ENGINEER FIELD MANUAL

PARTS I-VII

I. RECONNAISSANCE
II. BRIDGES
III. ROADS
IV. RAILROADS
V. FIELD FORTIFICATION
VI. ANIMAL TRANSPORTATION
VII. TABLES, WEIGHTS, MEASURES, AND SPECIFIC GRAVITIES

PREPARED UNDER THE
DIRECTION OF THE CHIEF OF ENGINEERS, U. S. ARMY

FIFTH (REVISED) EDITION

WASHINGTON
GOVERNMENT PRINTING OFFICE
1917

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1917

WAR DEPARTMENT.
Document No. 355.
Office of the Chief of Engineers.

1324060-306

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF STAFF,
Washington, November 19, 1909.

The Engineer Field Manual, United States Army, prepared under the direction of the Chief of Engineers, United States Army, is published for the information and guidance of all concerned; it will not be modified except by specific authority given in each case.

Any changes or suggestions that may occur to officers or others using the manual will be submitted to the Chief of Engineers for consideration in connection with the publication of future editions.

By order of the Secretary of War:

J. FRANKLIN BELL,
Major General, Chief of Staff.

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, March 12, 1907.

The ADJUTANT GENERAL.

SIR: 1. By authority of the Secretary of War, six parts of the Engineer Field Manual, compiled under the direction of this office by Lieut. Col. Smith S. Leach, Corps of Engineers and General Staff, have been published in five separate volumes. These parts are: Part I, Reconnaissance; Part II, Bridges; Part III, Roads; Part IV, Railroads, and Part V, Field Fortification (in one volume); and Part VI, Animal Transportation. Each of these six parts received the approval of the Chief of Staff before its publication.

2. It is now desired to publish under a single cover these six parts, revised and corrected, for issue to the service when ready for distribution.

3. In addition to the correction of such errors as have been discovered in the original editions it is proposed to add some new matter to bring the work up to date. The most important addition is a description of the new types of instruments adopted in 1906. It is also desired to add, in Part I, a brief description of the new military survey of Cuba; some additional topographical signs and symbols recently prescribed by the General Staff, and a brief account of the new system of angular measurement in *mils* adopted for position finding by the Field Artillery; to incorporate, in Part II, a very useful table of dimensions of floor systems for stated loads and spans, and to incorporate, in Part V, a plate and description of the Fort Riley redoubt, which presents several excellent features of design. It is proposed to add the new matter at convenient places as nearly in its topical relation as possible, but under a caption "Addenda, 1907."

4. The mechanical work involved in the preparation and publication of this revised edition would be, roughly, as follows: Drawing and engraving of four or five plates; making of a consolidated index; composition of the equivalent of about three or four pages of text; composition of consolidated index (about 48 pages); electrotyping of new plates, new pages of text, and new index; repaging of Parts II to VI, both inclusive, and printing and binding of 1,000 copies of the complete work, the cover to have a pocket, a pencil tube, and a broad flap folding over the back. The manuscript of a proposed introduction and list of authorities is inclosed.

5. The matter in the six parts as now published is electrotyped; the electrotype plates are at the Government Printing Office. The expense of drawing and engraving the new plates, of preparing the new matter, and of making the consolidated index would be chargeable to the appropriation carried by the Army appropriation act approved June 12, 1906, "For pontoon material, tools, instruments, and supplies required for use in the engineer equipment of troops, including the purchase and preparation of engineer manuals," of which there is an available balance sufficient for the purpose; the expense of composition, electrotyping, repaging existing electrotype plates, and of printing and binding to be borne by the appropriation for public printing and binding. The paper for the work is on hand in this office.

6. I have the honor to recommend that 1,000 copies of the revised edition of the six parts of the Engineer Field Manual, as hereinbefore described, and their accompanying plates be printed at the Government Printing Office and furnished for the use of this office on the usual requisition, the cost to be paid as stated in the preceding paragraph.

7. A copy of each of the parts as published is submitted herewith.

Very respectfully,

A. MACKENZIE,
Brig. Gen., Chief of Engineers, U. S. Army.

ENGINEER FIELD MANUAL.

INTRODUCTION.

In April, 1899, the Chief of Engineers directed the commandant of the Engineer School to enter upon the preparation of an Engineer Field Manual. At the same time all officers of the Engineer Corps who had been in the field during the Spanish War were invited to contribute data and suggestions, and many of them did so. At the Engineer School the work of compilation was committed to the instructor in civil engineering, then Capt. Henry Jervey, and under his control, and mostly by his own hand, a general plan of a manual was worked out, manuscript and plates prepared on the subjects of reconnaissance and bridges, and more or less complete notes on roads and railroads.

The instructions of the Chief of Engineers required a topical division and publication by parts, as completed. The part on reconnaissance was published in tentative form and distributed to officers of Engineers and other arms and to a few civil engineers, for comment and criticism. The parts on bridges and roads were sent in manuscript to certain Engineer officers for like criticism. As a result, the method of treatment of subject-matter and the mechanical features of the book were definitely determined and it was decided to revise the work already done to conform it to the modified plan and to republish Part I.

At this stage, 1903, the pressure of work at the Engineer School made it necessary to place this duty in other hands and it was devolved upon the commanding officer of the First Battalion of Engineers, and shortly thereafter the relation of that officer to the preparation of the manual was made personal, instead of ex officio, and all subsequent work has been by the same hand.

By July 1, 1906, six parts had been published—reconnaissance, bridges, roads, railroads, field fortification, and animal transportation. These parts are now collected in a single cover, with corrections of errors which crept into the first edition and some additions of new matter which has become available since the first publication. The most important of these additions, made by direction of the Chief of Staff, is the incorporation of the signs, etc., for finished maps, published by authority of the Secretary of War in 1904. A few minor changes which have been approved will be noted.

The opportunity now first offers to make acknowledgement of sources from which material has been drawn and of assistance rendered by persons in the preparation and publication of the manual.

As to authorities, a list is appended of works which have been consulted and from which facts or suggestions have been derived. Other works have been consulted, but nothing having been taken from or suggested by them, they are not mentioned. The titles in the list which appear in full-face type have been relied upon, more or less, as standard and as guides to topics and arrangement. But a single work seems to deserve further mention, and that is the incomparable Trautwine, the indebtedness to which is too obvious to require mention, but too important to permit it to be dispensed with. Substantially no matter from any source is quoted. The exigency of space required everything used to be rewritten with a view to condensation. In addition to the works cited, much valuable information, especially as to railroads and field fortifications, was obtained from the reports of military observers with the Japanese and Russian Armies and from fugitive publications as to the war in Manchuria. Of the latter, the Journal of the Royal Engineers of Great Britain deserves special mention.

Personal assistance in the preparation of text has come exclusively from brother officers of the Corps of Engineers, with the single exception of "Landscape sketching," paragraph 85, and plates 39 and 40, "Reconnaissance," which was abstracted from material furnished by Prof. C. W. Larned of the Military Academy. In verifying, criticizing, and correcting the work of the compiler, many officers have rendered assistance in greater or less degree, and none who have had opportunity to assist have refused. But a few have given so much of time and labor as to make mention by name an act of simple justice. Lieut. Col. Abbot, who has handled the manual in the office of the Chief of Engineers during the entire period of preparation and publication, has contributed never-failing enthusiasm, encouragement, and counsel, which have been of the greatest possible assistance. Maj. Rees read critically the parts on reconnaissance, bridges, and roads. Maj. Sibert and Lieuts. Johnston and Spalding did the same for railroads. Capt. Connor read the same part and forwarded a paper of his own on the subject, from which some suggestions were taken. Maj. Gaillard read the parts on field fortification and animal transportation and made valuable suggestions from personal experience with pack trains. Capt. Cheney read the part on animal transportation and made valuable suggestions. This part was also read by Dr. Hunter, V. S., Sixth Cavalry, and Mr. Daly, chief packer, upon whose approval much of its value rests. The original drawings for Parts I and II were made by enlisted men of the Second Battalion of Engineers, under the supervision of Maj. Judson, instructor of military engineering at the Engineer School. The names of these men unfortunately have not been made of record. These drawings were revised and those for Parts III and VI made by Sergt. Pihlgrem, of the First Battalion of Engineers, assisted for a short time by Corp. Flugel of the same organization. The drawings for Parts IV and V and the Addenda were made by Mr. S. P. Hollingsworth, of Washington, D. C. The indexing, partial and consolidated, was done by Mr. G. T. Ritchie of the Library of Congress. Mr. Pickering Dodge, chief clerk, United States Engineer Office, Washington, D. C., contributed valuable assistance in final proof reading.

LIST OF BOOKS CONSULTED.

Theory and Practice of Surveying. Johnson.
Military Topography and Sketching. Root.
Tables and Formulæ. Lee.
Higher Surveying. Gillespie.
Roads and Railroads. Gillespie.
Engineer's Pocketbook. Trautwine.
U. S. Bridge Equipage and Ponton Drill.
Military Bridges. Haupt.
Roads and Pavements. Baker.
Masonry Construction. Baker.
Highway Construction. Byrne.
Economic Railroad Location. Wellington.
Railroad Construction. Webb.
Notes on Track. Camp.
Railroad Curves. Allen.

The Railroad Spiral. Searles.
The Roadmaster's Assistant. Railroad Gazette.
Locomotive Breakdowns. Emergencies, and their Remedies. Fowler.
Text-book on Locomotives. International Correspondence Schools.
Train Rules and Train Dispatching. Dalby.
Block Signal Operation. Derr.
Letters of an Old Railway Official. Hine.
Manual of Field Engineering. Beach.
Field Fortification. Fiebeger.
Manual of Military Engineering. Ernst.
Attack of Fortified Places. Mercur.
Royal Engineers Aide Memoire.
Handbook of Modern Explosives. Eissler.
Woolwich Text-book, Parts I and II.
Chatham Text-book, Parts II and III.
Text-book of Field Engineering. Phillips.
Field Fortification. Hutchinson.
British Manual of Field Engineering. 1903.
Destruction of Obstacles in Campaign. Bornecque, Tr. Burr.
U. S. Field Service Regulations.
Manual of the Quartermaster's Department, U. S. Army.
Horses, Saddles, and Bridles. Carter.
Packer's Manual. Daly.
Treatise on Feeding and Training of Mules. Riley.
Military Transport. Furse.

PART I.

RECONNAISSANCE.

PART I—RECONNAISSANCE.

1. **Topographical reconnaissance**, as here treated, covers the instruments and methods necessary for the production of maps of **SMALL AREAS** and routes of travel of sufficient accuracy for temporary military needs.

No reconnaissance sketch or combination of sketches can be expected to cover with sufficient accuracy an area of more than about 2 miles on a side. Areas up to 10 miles on a side can be satisfactorily mapped for military purposes by running transit or plane table control traverse lines which will locate some landmark in each square mile, adjusting the traverses, plotting the adjusted traverses, and then filling in the control skeleton thus obtained by sketching.

For larger areas triangulation or traverse control of greater accuracy is necessary and the curvature of the earth soon becomes a factor. No map of an area over 10 miles on a side should be undertaken without a thorough knowledge of the best modern practice in topographic mapping such as that followed by the United States Geological Survey.

2. The information to be obtained in a topographical reconnaissance may be grouped under the headings of **time, cover, resources,** and **nomenclature.** The map should permit a determination of the time which a column will require to pass between any two given points by showing the distance between them and the condition of the road or country which must be traversed, as regards its effect on the rate of march; the accidents of ground which will afford cover to the army or to the enemy; the location, quantity, and quality of water, fuel, grass, etc., and should give to each feature its local name. The last requirement is of great importance and is the one most often neglected.

3. **The fundamental topographical operation** is the determination of the direction and distance of one point from another point.

The direction of one point from another is composed of two elements: First, the angle made by the line joining the two points, with a *vertical* plane passing through one of them. This angle is measured in a horizontal plane and is called the **azimuth;** second, the angle made by the line joining the two points, with a *horizontal* plane passing through one of them. This angle is measured in a vertical plane passing through both points, and for convenience will be called the **gradient.**

4. **Azimuths.**—As an infinite number of vertical planes may pass through a given point, it is necessary to select one as the origin of azimuths. In topographical reconnaissance the plane selected is that of the magnetic meridian at the point. Its direction *in a horizontal plane* is the line of rest of a freely suspended and balanced magnetic needle, and this line is the origin of azimuths.

From this origin azimuths are measured in degrees of arc from 0 to 360, passing from the north point through the east, south, and west to north again. Azimuths of 0° to 90° are in the northeast or first quadrant (fig. 1); those of 90° to 180° are in the southeast or second quadrant; those from 180° to 270° in the southwest or third quadrant, and those from 270° to 360° in the northwest or fourth quadrant.

Azimuths are bearings between stations taken in the direction of progress of the reconnaissance. Bearings taken in the other direction are called **back azimuths.** If the stations are numbered in the order they are occupied, a bearing from a lower to a higher numbered station is an azimuth, and a bearing from a higher to a lower numbered station is a back azimuth.

The method of stating azimuths described above is that commonly used in surveying when direction is maintained by **carrying an azimuth.** It is the simplest to understand and use, and permits the angle between any two lines to be read at a glance.

There are other ways of expressing azimuths, adapted to special conditions or circumstances. In astronomical work and tables the azimuth is reckoned from the **south,** through W., N., and E., 360° to south again. Any astronomical azimuth differs from the corresponding survey azimuth by 180°.

In navigation azimuths are reckoned from the **mariner's compass,** and are called **bearings.** The dial is divided into 32 **points** and each point into **quarter points.** The names of the points and their relation to survey azimuths are shown in figure 1.

Land surveyors reckon bearings in both directions from N. and S. Their compasses are graduated 90° in each direction from the N. and S. points and a bearing is stated by giving the angle and direction from N. or S., whichever may be nearest, as N. 46° W., S. 29° E.

Formerly such bearings were reckoned from the nearest cardinal point, N., S., E., or W., as W. 40° N., which corresponds to N. 46° W. This method is very convenient for giving directions in orders and reports. It is shown in the middle circle of figure 1.

5. A special method of azimuth measurement has been adopted for use in the fire control of field artillery. The unit, called a **mil,** is the arc whose length is one one-thousandth of the radius. By computation this arc is 3'.437+. This length is not commensurate with the length of the circle being contained in it 6,283.24 times. For convenience of graduation, the circle is divided into 6,400 equal parts, assumed to be mils, the angular value of each of which is 3'.375, differing from the computed value by nearly 2 per cent, which error enters into all determinations and is neglected.

Each change of 1 mil in azimuth corresponds to a change in position in a direction perpendicular to the line of sight of one one-thousandth of the range. This method reduces all elements of fire control to functions of the range.

6. The **compass** is the standard instrument for the determination of azimuths in topographical reconnaissance. It consists of *case, needle, card, pivot,* and *stop,* figures 2 and 3.

The **card** may be **fixed** to the case or **movable,** attached to the needle and revolving with it. The stop raises the needle from the pivot and clamps it against the glass cover. A good compass must have a needle sufficiently magnetized to settle accurately and a pivot free from rust and roughness. If the needle becomes too weak, it may be remagnetized by rubbing gently from pivot to point on a permanent or electro magnet, each end of the needle to be rubbed on the pole which attracts it. In returning the needle for another stroke carry it a foot or more from the magnet. The pivot may be polished with Putz pomade or similar substances on a soft stick.

If possible, however, turn in the defective compass and get a good one in place of it.

A needle loses part of its magnetism if kept for a long time out of the plane of the magnetic meridian. In storing a compass care should be taken to place it in the case or on the shelf with the N. end of its needle pointing north.

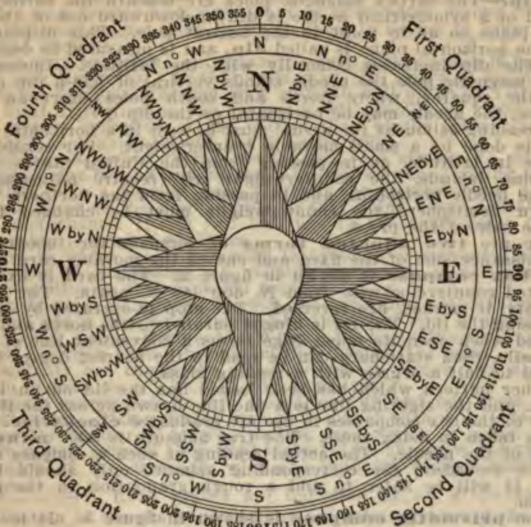


Fig. 1

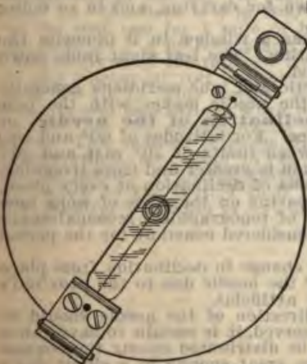


Fig. 3

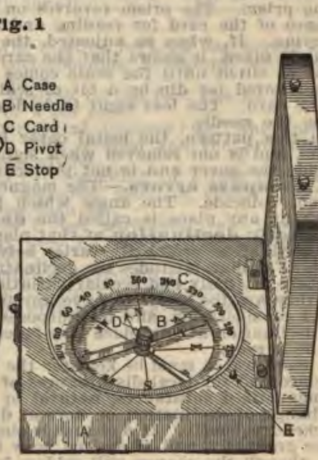


Fig. 2

7. **Dip.**—The earth's magnetic poles are beneath the surface, and the end of a symmetrical needle is drawn downward out of the horizontal plane so as to point to the nearest pole. This displacement from the horizontal plane is called **dip**, and is measured in degrees of arc. The dip increases generally with the latitude. Immediately over a magnetic pole the needle stands vertical or has a dip of 90°. Near the equator, where north and south poles exert an equal influence, the needle may be horizontal or the dip 0.

For reading azimuths the needle must be kept in a horizontal plane, which is done by a small movable counterweight. For considerable changes in latitude, as in passing from the United States to the Philippine Islands, the counterweight will require adjustment to keep the needle horizontal, and in passing from the northern to the southern hemisphere the counterweight must be changed to the opposite side of the pivot.

There are **two adopted forms** of compass for topographical reconnaissance, one of the fixed and one of the movable card type.

The **box compass** is shown in figure 2. The card is fixed and graduated counterclockwise from N. 360° to N. again. The E. and W. points, if marked, are reversed. The stop is operated by opening and closing the lid. The lid is hinged parallel to the north and south line, and when open its upper edge forms a convenient line of sight. The needle when stationary can be read to the nearest degree by the eye, and to half a degree with a reading glass.

Another pattern which has been issued has the lid on an E. and W. side, and the sighting line is a fine line drawn across the lid.

Some of the box compasses in use are graduated **clockwise.** Care must be taken in using these. The true azimuth is 360° **minus** the reading of the needle. The actual reading of such a compass should never be recorded; the corresponding azimuth only should be set down. It will be safer to add a rough graduation in the proper direction.

8. The **prismatic compass** is shown in figure 3. It is of the movable-card type. It is read through a reflecting inverting magnifying prism. The prism revolves on an axis and is over the circumference of the card for reading and against the edge of the case for carrying. If, when so adjusted, the scale is out of focus when the sight is taken, it shows that the card is not horizontal, and the case must be tilted until the scale comes into focus. The needle may be compensated for dip by a bit of sealing wax stuck on the underside of the card. The leaf sight folds down for carrying, and in so doing stops the needle.

In this pattern, the metal cover has a window in it opposite the prism, and is not removed when sighting. The leaf sight folds down outside the cover and is not protected.

9. **Compass errors.**—The magnetic and true meridians generally do not coincide. The angle which the needle makes with the true north at any place is called the **declination of the needle**, or **magnetic declination** at that place. For latitudes of 60° and less the declination ordinarily varies between limits of 20° east and 20° west. For high latitudes the declination is greater and more irregular.

There are daily and secular variations of declination at every place, but they are too small to have any bearing on the class of work now under consideration, and for purposes of topographical reconnaissance the declination at any place may be considered constant for the period of the survey.

A close watch must be kept for the change in declination from place to place and for local disturbances of the needle due to the proximity of magnetized substances, natural or artificial.

Change of declination or *normal* direction of the needle should be checked frequently. If a change is observed, it is certain to have taken place gradually, and, if desired, may be distributed among the courses run, though the change will seldom be great enough in a single day's work to make its distribution practicable.

Abnormal deflections of the needle, due to local disturbances, are sudden and erratic and should not be distributed among all the courses, but only among those in which there is reason to believe the disturbance occurs.

A simple way to detect—not measure—such disturbances is to take frequent back azimuths. If the position of the needle is normal at both stations, the azimuths and back azimuth will differ by 180°. If there is local attraction on the course, it will usually be stronger or cause a greater deflection at one station than at the other, and the azimuth and back azimuth will not differ by 180°.

Another way is, when taking the bearing to a station, to select a well-defined point beyond and on the same course. On arriving at the new station, take a bearing from there to the selected point ahead. If it is the same as the first bearing to that point, there probably is no local disturbance. If the two bearings to the same point differ, there probably is local disturbance.

A course in which local attraction is detected or suspected should be noted, and if, on closing, an azimuth correction is necessary, it should be applied to the suspected courses.

10. **Gradients.**—There can be but one horizontal plane through a given point, and it may be determined by the spirit level or plumb line without serious error. Gradients are measured by taking the angle of the line of direction with a horizontal line through the point.

11. Gradients are commonly called *grades* or *slopes* and are expressed in degrees, as 1°, 2°, 3½°, 6¼° slope, etc.

Each angle corresponds to two slopes, one up and one down from the initial point. Rising grades may be recorded with a + before, or an R after the number of degrees; falling grades with — before, or F after. On a map, general slopes are indicated by an arrow pointing in the direction of the drainage, with the gradient written beside it, thus $\xrightarrow{\quad 4^\circ \quad}$. Road grades are indicated by an arrowhead at top and bottom of the grade, the one at top pointing toward the road and the one at bottom away from it, thus ↓.$\underset{4^\circ}{\rule{5em}{0.4pt}}$.↓

Gradients are also expressed by the relation between the change of elevation—rise or fall—and the corresponding horizontal distance. This relation is stated in various ways.

By the rise in feet per 100 feet horizon or the foot rise as a percentage, as "the slope is 4 in 100, or 4 per cent."

By the foot rise for 1 mile of horizontal distance; as "the grade is 50 feet," or "a 50-foot grade." This method and the preceding are commonly used for railroad track grades.

By the number of feet horizontal corresponding to 1 foot rise; as 3 **to** 1, 10 **to** 1. This method is commonly used for slopes of embankments and excavations when less than 45°.

By the foot rise corresponding to 1 foot horizontal; as, 1 **on** 1, 6 **on** 1. This method is commonly used for slopes of embankments and excavations, etc., from 45° to 75°.

By the number of inches horizontal corresponding to 1 foot rise; as, 3 inches to the foot, 1 inch in the foot. This method is commonly used for gradients of 70° and over and is called *batter*.

TABLE I.

12. **Comparison of the different methods of expressing gradients:**

In this table the different methods of expressing gradients have their values given for the usual range and to the customary degree of accuracy of their use.

Angle.	Feet per 100 feet horizontal or per cent.	Feet to the mile, horizontal.	1 vertical on or in—	1 horizontal to—	Batter inches to the foot.
Degrees.			*Horizontal.*	*Vertical.*	
¼	0.44	23	229	...	...
½	.87	46.1	115	...	...
¾	1.31	69.1	76	...	...
1	1.74	92.2	57	...	...
1¼	2.18	115.1	46	...	...
1½	2.62	138.3	38	...	...
1¾	3.06	161.2	33	...	...
2	3.49	184.4	29	...	...
2½	4.37	230.5	23	...	...
3	5.24	276.7	19	...	...
3½	6.12	322.9	16	...	...
4	6.99	369.2	14	...	...
4½	7.37	415.5	13	...	...
5	8.75	461.9	11.4	...	...
6	10.51	555	9.5	...	...
7	12.28	...	8.1	...	...
8	14.05	...	7.1	...	...
9	15.84	...	6.3	...	...
10	17.63	...	5.7	...	...
15	...	...	3.7	...	...
20	...	...	2.7	...	...
25	...	...	2.1	...	...
30	...	...	1.7	...	...
40	...	...	1.2	...	...
45	...	...	1	1	...
50	...	...	...	1.2	...
60	...	...	...	1.7	...
65	...	...	...	2.1	...
70	...	...	...	2.7	...
75	...	...	...	3.7	3¼
80	...	...	...	5.7	2⅛
81	...	...	...	6.3	1⅞
82	...	...	...	7.1	1¾
83	...	...	...	8.1	1½
84	...	...	...	9.5	1¼
85	...	...	...	11.4	1
85½	...	...	...	13	⅞
86	...	...	...	14	...
86½	...	...	...	16	¾
87	...	...	...	19	⅝
87½	...	...	...	23	½
88	...	...	...	29	...
88¼	...	...	...	33	⅜
88½	...	...	...	38	...
88¾	...	...	...	46	¼
89	...	...	...	57	...
89¼	...	...	...	76	...
89½	...	...	...	115	⅛
89¾	...	...	...	229	...

13. The **clinometer** is the instrument adopted for measuring gradients, with the horizontal plane indicated by a spirit level. It consists (fig. 4) of a sight tube, *A*, with a graduated vertical arc, *B*, fastened to it, and a level tube, *C*, with attached index arm, *D*, revolving about a horizontal axis through the center of the vertical arm. The base of the sight tube is a plane parallel to the line of sight. Under the center of the level tube is an opening in the sight tube, inside of which is a mirror occupying one-half the width of the sight tube and facing the eye end at an angle of 45° with the line of sight. A horizontal wire extends across the middle of the sight tube in front of the mirror. When the bubble is brought to the center, its reflected image seen from the eye end appears to be bisected by the wire.

The central position of the bubble indicates that the level tube is horizontal, and the reading of the index arm upon the arc is the angle between the axis of the level tube and the line of sight. This reading should be 0° when these lines are parallel. The vertical arc is graduated each way from 0° at its middle point. The index arm has a double vernier whose smallest reading is 10′ of arc. Gradients of more than 45° are difficult to measure on account of the foreshortening of the level tube as reflected in the mirror.

When the vernier is set at 0°, the instrument may be used as a hand level to locate points at the same elevation as the eye. The graduation on the inner edge of the vertical limb corresponds to the ordinary fractional method of indicating slopes, as 1 on 2, 1 on 10, etc. This scale should be read on the forward edge of the index arm, or in some forms on a special index mark on a shorter part of the arm.

The **level tube is made parallel to the sight tube** by the adjusting screws *E* (fig. 4). To test and correct the adjustment, place the instrument on a smooth surface, the more nearly horizontal the better, and mark carefully the position of one side and one end of the sight tube. Center the bubble by moving the index arm, and read the vernier. Reverse the instrument, bringing the other side and end of the sight tube to the marks. Center the bubble by moving the index arm, and read again. Note and record for each reading its direction from 0°, whether toward or away from the eye end of the sight tube. Note and record also the location of the eye end in each position with respect to some fixed object, so that the instrument can be replaced in the first position or second position at will.

If the first and second readings are the same, the adjustment is correct. If they differ, take the mean of the two and set the vernier at that reading on the side corresponding to the first reading. Place the instrument in the first position and bring the bubble to the center by means of the adjusting screws *E*. For a check, set the same reading on the side corresponding to the second reading and place the instrument in the second position. The bubble should come to the middle.

The **gravity clinometer** adopted in 1906 is shown in figure 5. It consists of a circular case in which is a graduated circle controlled by a pendulum. The line of sight is through the peep *L* and a glass-covered opening at *M*. The zero line is engraved on the glass. A mirror near the center reflects the scale back to the peep. Looking through the instrument the object is seen on the zero line, and at one end of the latter a graduation of the scale is visible. The graduations are from zero at the horizontal each way to 45°, the graduations and numbers for elevation being in red and those for depression in black.

A sliding bar at *H* unlocks the spring-controlled stop, which, when pressed, frees the pendulum and graduated circle, and when released stops them again.

To use, move the locking bar *F* to free the stop *H;* hold the instrument in the left hand with the forefinger on the stop; depress stop; bring line of sight on object and read.

Fig. 6

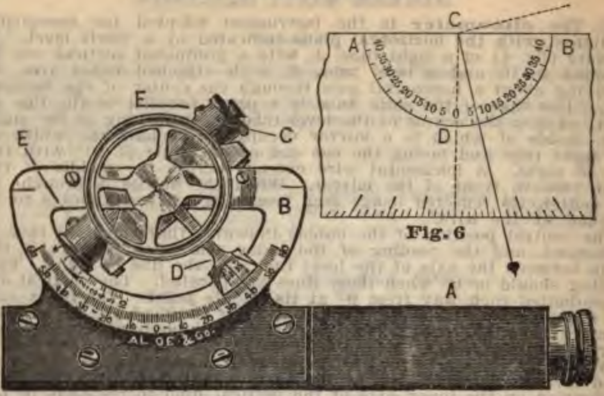


Fig. 4

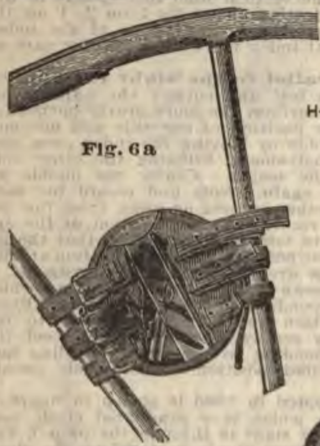


Fig. 6a

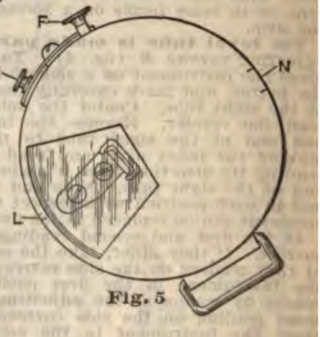
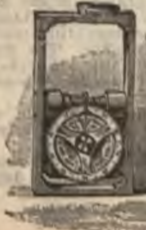


Fig. 5



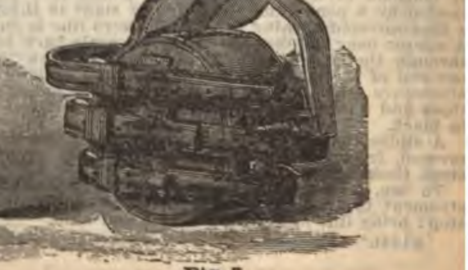


Fig. 8

Fig. 7

A type of **hand level** designed for slope readings is now generally preferred to the clinometer. This hand level has horizontal lines on the object glass, either reading degrees or per cent. With the per cent graduations it is possible to obtain differences of elevation without the necessity of using tables of degrees for differences of elevation, but the degree graduation is suited for use with the existing scales of slopes, and is generally preferred.

14. The **determination of gradients by the plumb line** is quicker and simpler, but less precise than with the clinometer, though exact enough for ordinary purposes. If a line of sight be taken along the edge of a board and a line be drawn on the board perpendicular to the sighting edge, this line, when the board is held in a vertical plane, will make the same angle with the plumb line that the sighting edge makes with the horizontal, or, in other words, will indicate the gradient (fig. 6.).

Such a construction is called a **slope board** and is readily improvised. The scale may be constructed by sweeping an arc of a circle *AB* (fig. 6) from the point *C*, at the intersection of the perpendicular and the sighting edge. From the perpendicular at *D* lay off each way on the arc chords equal in length to the radius *CD* divided by 57.3. It is convenient to take a radius of 5.73 inches, or $5\frac{3}{4}$ inches scant, when the chords will be $\frac{1}{10}$ inch, or a radius of $7\frac{3}{16}$ inches, when the chords will be $\frac{1}{8}$ inch, accordingly as the scale used is graduated to tenths or eighths.

Short radial lines drawn at the ends of the chords form a graduation in degrees. The scale may be drawn on the lower edge of the board by prolonging the radial lines as indicated in the figure. The plumb line is suspended from the point *C*.

In use, the board is held so that the plumb line swings free but very close to the board. The sighting edge is directed to the object and when the line is steady the board is quickly tilted so that the line draws across the edge. The board is then turned to a horizontal position or nearly so, and the reading taken; or, when the line is steady, it may be pressed against the board with the finger and held in place until the reading is taken. With a straight scale and for steep grades the latter method is better.

15. **Elevations.**—From the **slope** and **distance** the elevation of a point above an assumed plane of reference may be derived. The **difference of height** of any two points is known by comparing their elevations above a common plane, called the **plane of reference**, or **datum.**

The plane of reference is taken low enough so that no point of the area to be covered by the reconnaissance will be below it. This makes all elevations positive. Knowing the height of a point above this plane of reference, the elevation of any other point may be obtained by taking the gradient and distance to that point, deriving from them the difference of height between the two points, and adding this difference to the elevation of the first point if the gradient is rising, or subtracting it if the gradient is falling.

The elevation for a given gradient and distance depends upon whether the distance is measured *along the gradient* or *along the horizontal*. Distances paced are along the gradient. Those measured with a chain will also usually be on the slope, though sometimes care is taken to hold the chain horizontal, in which case the table for horizontal distances is to be used. Those determined by intersections or scaled from a map are along the horizontal.

The differences of elevation corresponding to various gradients and any distances may be taken from the following tables:

TABLE II.

16. **Differences of elevation** for gradients of 0° to 30°, and horizontal distances.

Gradient in degrees.	Difference of elevation for horizontal distances of—								
	1	2	3	4	5	6	7	8	9
½	00087	00174	00261	00348	00435	00522	00609	00696	00783
1	00174	00340	00523	00698	00872	01047	01221	01396	01570
1½	00262	00524	00786	01048	01310	01572	01834	02096	02358
2	00349	00698	01047	01396	01745	02094	02443	02792	03141
2½	00436	00872	01308	01744	02180	02616	03052	03488	03924
3	00524	01048	01572	02096	02620	03144	03668	04192	04716
4	00699	01398	02097	02797	03496	04195	04894	05594	06293
5	00875	01750	02625	03500	04375	05250	06125	07000	07875
6	01051	02102	03153	04204	05255	06306	07357	08408	09459
7	01228	02456	03684	04912	06140	07368	08596	09824	11052
8	01405	02810	04216	05621	07027	08432	09837	11243	12648
9	01584	03168	04752	06336	07920	09504	11088	12672	14256
10	01763	03526	05289	07053	08816	10579	12343	14106	15869
12	02125	04251	06376	08502	10628	12753	14879	17004	19130
14	02493	04986	07479	09973	12466	14059	17453	19946	22439
16	02867	05734	08602	11469	14337	17204	20071	22939	25806
18	03249	06498	09747	12996	16245	19494	22743	25992	29241
20	03639	07279	10919	14558	18198	21838	25477	29117	32757
22	04040	08080	12120	16161	20201	24241	28282	32322	36362
24	04452	08904	13356	17809	22261	26713	31166	35618	40070
26	04877	09754	14631	19509	24386	29263	34141	39018	43895
28	05317	10634	15951	21268	26585	31902	37219	42536	47853
30	05773	11547	17320	23094	28867	34641	40414	46188	51961

The difference of elevation for *any* gradient and *any* horizontal distance may be obtained by multiplying the distance by the **tang.** of the angle or gradient, Table XIV.

TABLE III.

17. **Differences of elevation** for gradients of 0° and 30°, and distances measured on the slope.

Gradient in degrees.	Difference of elevation for sloping distances of—								
	1	2	3	4	5	6	7	8	9
½	00087	00174	00262	00349	00436	00523	00611	00698	00785
1	00174	00349	00523	00698	00873	01047	01222	01396	01571
1½	00262	00523	00785	01047	01309	01571	01832	02094	02356
2	00349	00698	01047	01396	01745	02094	02443	02792	03141
2½	00436	00872	01308	01745	02181	02617	03053	03489	03926
3	00523	01047	01570	02093	02617	03140	03663	04187	04710
4	00697	01395	02093	02790	03488	04185	04883	05580	06278
5	00871	01743	02615	03486	04358	05229	06101	06972	07844
6	01045	02090	03136	04181	05226	06272	07317	08362	09407
7	01219	02437	03656	04875	06093	07312	08531	09749	10968
8	01392	02783	04175	05567	06959	08350	09742	11134	12525
9	01564	03129	04693	06257	07822	09386	10950	12515	14079
10	01736	03473	05209	06946	08682	10419	12155	13892	15628
12	02079	04158	06237	08316	10395	12475	14554	16633	18712
14	02419	04838	07258	09677	12096	14515	16934	19354	21773
16	02756	05513	08269	11025	13782	16538	19294	22051	24807
18	03090	06180	09270	12361	15451	18541	21631	24721	27811
20	03420	06840	10261	13681	17101	20521	23941	27362	30782
22	03746	07492	11238	14984	18730	22476	26222	29968	33714
24	04067	08135	12202	16269	20337	24404	28471	32539	36606
26	04384	08767	13151	17535	21918	26302	30686	35070	39453
28	04695	09389	14084	18779	23473	28168	32863	37558	42252
30	05000	10000	15000	20000	25000	30000	35000	40000	45000

The difference of elevation for *any* sloping distance and *any* angle or gradient may be found by multiplying the distance by the **sine** of the angle, Table XIV.

Explanation of use of Tables II and III:

Rule.—From the line of the given gradient, take out the tabular numbers corresponding to each of the figures of the given distance, *beginning* at the *right*, and set them down; each one place to the left of the one above it. Retain the ciphers at the beginning of the last tabular number taken out, if any. Other left-hand ciphers may be dropped.

Add the tabular numbers, and point off from the *left* the number of places equal to that of the left-hand figure of the distance, *counting any left-hand ciphers*. The result is the difference of elevation, in the same unit as the distance.

Examples.—For the difference of elevation corresponding to a gradient of 3° and a distance of 6,273 feet on the slope—

From Table III—

For 3 opp. 3° and under 3,	1570	
For 7 opp. 3° and under 7,	3663	
For 2 opp. 3° and under 2,	1047	
For 6 opp. 3° and under 6,	03140	retain leading cipher.
As 6 is in 4th place, point off 4,	0328. 2900	
Diff. of elevation =	328. 29	ft.

24. What difference of elevation for gradient of 5°, and horizontal distance of 7,180.56 yards?

From Table II—

Opp. 5° and under 6,	5250	
Opp. 5° and under 5,	4375	
Opp. 5° and under 8,	7000	
Opp. 5° and under 1,	875	
Opp. 5° and under 7,	06125	retain leading cipher.
7 is in 4th place, point off 4,	0628. 299000	
Diff. of elevation =	628. 299	yds.

18. **Barometric leveling.**—The weight of the atmosphere at sea level is 14.703 pounds per square inch, equal to the weight of a column of mercury 29.92 inches high, or a column of fresh water 34.7 feet high.

The **aneroid barometer** records the pressure of the atmosphere in inches, the same as a mercurial barometer, the reading being taken from a pointer moving on a circular scale. The corresponding elevation in feet is also shown on the dial of the aneroid barometer. It must be carefully handled as it is sensitive to shocks. A screw head will be seen through a hole in the back of the outer case by which the needle may be brought to any desired reading, and the instrument corrected whenever it can be compared with a standard. With the aneroid, corrections for instrumental temperature can not be made, and for this reason small pocket instruments are preferable, as carried in the pocket they are not exposed to so great changes in this respect.

The **pressure of the atmosphere varies** with the altitude above sea level, and it also varies with the moisture, temperature, and latitude, which do not depend upon the altitude.

In measuring altitudes with the barometer these other causes of variation must be eliminated so far as possible. It is best done by simultaneous observation at both stations. If the stations are not far apart all disurbing conditions will be substantially the same at each and therefore eliminated, except temperature, which, with considerable difference of altitude, will always be less at the upper than at the lower station.

If *simultaneous* observations *can not* be made, the stations should be occupied with as *little interval of time* between as possible, and better results will be obtained if the time of observation can be so chosen as to take advantage of calm, bright, dry weather.

When the hygrometric conditions are very uniform an aneroid read at intervals on a day's march over a rough country will give a fairly good idea of the profile.

TABLE IV.

19. **Table of elevations** above sea level from barometer readings (United States Coast and Geodetic Survey), for mean hygrometric conditions and mean temperature of 50° F.:

Barometer reading.	Altitude above sea level.	Diff. for 0.01″.	Barometer reading.	Altitude above sea level.	Diff. for 0.01″.	Barometer reading.	Altitude above sea level.	Diff. for 0.01″.
Inches.	*Feet.*	*Feet.*	*Inches.*	*Feet.*	*Feet.*	*Inches.*	*Feet.*	*Feet.*
18.0	13,918	−15.1	22.2	8,204	−12.2	26.4	3,483	−10.3
.1	13,767	15.0	.3	8,082	12.2	.5	3,380	10.3
.2	13,617	14.9	.4	7,960	12.2	.6	3,277	10.2
.3	13,468	14.9	.5	7,838	12.1	.7	3,175	10.2
.4	13,319	14.7	.6	7,717	12.0	.8	3,073	10.1
.5	13,172	14.7	.7	7,597	12.0	.9	2,972	10.1
.6	13,025	14.6	.8	7,477	11.9	27.0	2,871	10.1
.7	12,879	14.6	.9	7,358	11.9	.1	2,770	10.0
.8	12,733	14.4	23.0	7,239	11.8	.2	2,670	10.0
.9	12,589	14.4	.1	7,121	11.7	.3	2,570	10.0
19.0	12,445	14.3	.2	7,004	11.7	.4	2,470	9.9
.1	12,302	14.2	.3	6,887	11.7	.5	2,371	9.9
.2	12,160	14.2	.4	6,770	11.6	.6	2,272	9.9
.3	12,018	14.1	.5	6,654	11.6	.7	2,173	9.9
.4	11,877	14.0	.6	6,538	11.5	.8	2,075	9.8
.5	11,737	13.9	.7	6,423	11.5	.9	1,977	9.8
.6	11,598	13.9	.8	6,308	11.4	28.0	1,880	9.7
.7	11,459	13.8	.9	6,194	11.4	.1	1,783	9.7
.8	11,321	13.7	24.0	6,080	11.3	.2	1,686	9.7
.9	11,184	13.7	.1	5,967	11.3	.3	1,589	9.7
20.0	11,047	13.6	.2	5,854	11.3	.4	1,493	9.6
.1	10,911	13.5	.3	5,741	11.2	.5	1,397	9.6
.2	10,776	13.4	.4	5,629	11.1	.6	1,302	9.5
.3	10,642	13.4	.5	5,518	11.1	.7	1,207	9.5
.4	10,508	13.3	.6	5,407	11.1	.8	1,112	9.5
.5	10,375	13.3	.7	5,296	11.0	.9	1,018	9.4
.6	10,242	13.2	.8	5,186	10.9	29.0	924	9.4
.7	10,110	13.1	.9	5,077	10.9	.1	830	9.4
.8	9,979	13.1	25.0	4,968	10.9	.2	736	9.3
.9	9,848	13.0	.1	4,859	10.8	.3	643	9.3
21.0	9,718	12.9	.2	4,751	10.8	.4	550	9.2
.1	9,589	12.9	.3	4,643	10.8	.5	458	9.2
.2	9,460	12.8	.4	4,535	10.7	.6	366	9.2
.3	9,332	12.8	.5	4,428	10.7	.7	274	9.2
.4	9,204	12.7	.6	4,321	10.6	.8	182	9.1
.5	9,077	12.6	.7	4,215	10.6	.9	91	9.1
.6	8,951	12.6	.8	4,109	10.5	30.0	00	9.1
.7	8,825	12.5	.9	4,004	10.5	.1	− 91	9.0
.8	8,700	12.5	26.0	3,899	10.5	.2	−181	9.0
.9	8,575	12.4	.1	3,794	10.4	.3	−271	9.0
22.0	8,451	12.4	.2	3,690	10.4	.4	−361	9.0
.1	8,327	12.3	.3	3,586	10.3	.5	−451	8.9

TABLE V.

20. Coefficients for temperature correction.—Argument $(t+t')$=Sum of temperatures at the two stations:

$t+t'$.	Coefficient C.	$t+t'$.	Coefficient C.	$t+t'$.	Coefficient C.
°		°		°	
0	−0.1024	60	−0.0380	120	+0.0262
10	−0.0915	70	−0.0273	130	+0.0368
20	−0.0806	80	−0.0166	140	+0.0472
30	−0.0698	90	−0.0058	150	+0.0575
40	−0.0592	100	+0.0049	160	+0.0677
50	−0.0486	110	+0.0156	170	+0.0779
60	−0.0380	120	+0.0262	180	+0.0879

Examples:

Station.	Barometer.	Temperature.
	Inches.	°*F.*
Sacramento	30.014	59.9
Summit	23.288	42.1

From table of elevations.......... Sacramento = −12.7

Summit = 6,901.0

Diff. = 6,913.7

$t+t'$ = 102°

∴ C = +0.0070

∴ Temperature correction, 6,913.7 × 0.007 = +48.4

H = 6,962.1 feet.

Station.	Barometer.	Temperature.
	Inches.	°*F.*
Lower	28.675	57.3
Upper	22.476	38.5

From table of elevations........... Lower = 7,367.0

Upper = 1,307.0

Diff. = 6,060.0

$t+t'$ = 95°.8

∴ C = +0.0004

∴ Temperature correction, 6,060 × 0.0004 = +2.4

H = 6,062.4 feet.

21. ***Use of compasses.***—A good needle requires time to settle even when the case is firmly supported, and the user should cultivate the knack of catching it at the middle of its swing, which is the desired reading. If the compass can be supported, it is always better to do *Then* the sight can be carefully taken and the position of the

eye changed to read the needle. Wait till the swing gets down to 4° or 5°, which it will usually do in a few seconds. Then catch the highest and the lowest readings on the same swing and take their mean for the true reading. If the first swings are very large, catch the needle with the stop near the middle of the swing and release it quickly. This will suddenly check the swings and shorten the time in which the readings can be taken.

In using the box compass without a support hold it sufficiently below the eye, so that the swing of the needle can be seen. Point the edge of the lid in the required direction, catch the needle with the stop in the middle of a swing and hold it stopped until the reading is taken. Stop readings are less accurate than sight readings, as the needle may be displaced slightly when off the pivot. When the stop is used press it quickly and firmly. Always sight a *fixed-card* compass from the south end of the card and read the north end of the needle.

With the prismatic compass the stop is not used except to check the swings. Utilize a support if practicable. The prism having been adjusted for focus, as already explained (par. 8), adjust the case so as to bring the scale into focus, and when the swings become small read the extremes and take the mean.

Compasses for night marching are on the market, but are not very reliable. They have the dial rendered luminous by a paint. After exposure to the sun or strong daylight they give off light, at first rather strong, but rapidly diminishing in intensity. After a few hours they are not bright enough to be of much use.

The surest preparation for night marching is a provision for illuminating the compass by ordinary means without allowing the light to be seen.

22. **To determine the declination of the compass:**

First method; from the sun.—Prick a small hole in a piece of tin or opaque paper and fix securely over the south edge of a table or other surface perfectly level, so that the sunlight coming through the hole will fall on a convenient place on the surface (fig. 9). The hole may be 2 feet above the table for long days and 18 inches for short ones. Half an hour before to half an hour after noon mark the position of the spot of sunlight on the horizontal surface at equal time intervals of about 10 minutes. Draw a curve as *bd* (fig. 9), through the points marked, and from point *c* in the horizontal surface and in a vertical line with the hole *a* sweep an arc *ef* intersecting *bd* in two points. The line *cg*, drawn from *c* through a point on the arc midway between the intersection, is the true meridian. The line *bd* illustrates the method merely. Its form varies with the sun's declination.

Second method; from the sun or a star.—Observe the magnetic bearing of the sun, a planet, or a bright star at rising and setting on the same day, or at setting on one day and at rising on the next. Take the difference between the sum of the rising and setting azimuths and 360°. One-half of this difference is the declination of the compass or variation of the needle, *east* if the sum of the azimuths is *less* than 360°; *west*, if it is *greater*. **In using this method,** the observations are better taken when the object is just above the true horizon, or at a gradient of zero. This can usually be done if a high point is chosen for the observations. **If it can not be done,** be careful to take both observations with the object at the same gradient. **This is most important with the sun.** Under the least favorable conditions an inequality of 1° in the gradients at the times of observation on the sun may introduce an error of ½° in the result. If using a star, choose one which rises nearly east from the point of observation, and the inequality of a degree in gradients will not be material.

The change in declination of the sun between observations can not affect the result more than ¼°.

Both observations need not be made at the same point, but should not be more than 10 miles apart in east and west or north and south directions.

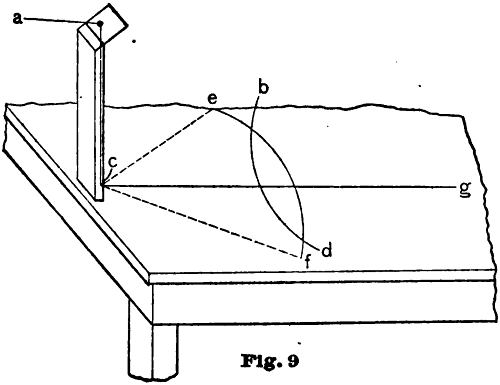


Fig. 9

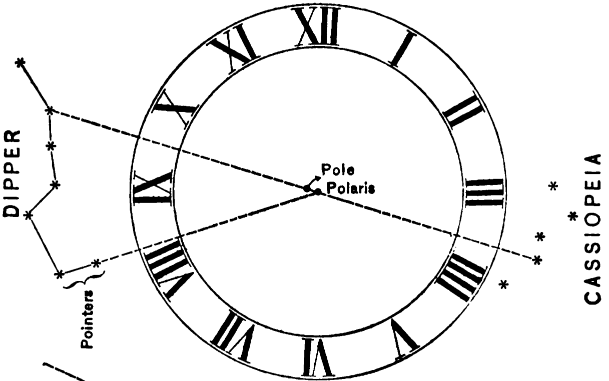


Fig. 10

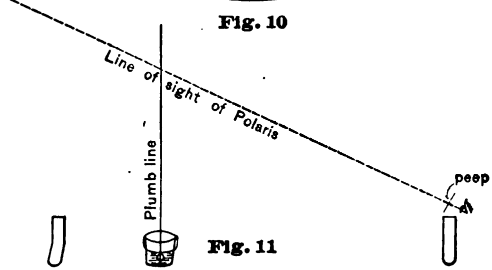


Fig. 11

The *two foregoing methods* are applicable in the *northern* or *southern* hemisphere.

Third method; from Polaris.—The true north pole is about 1° 12′ distant from Polaris on a line joining that star with one in the handle of the dipper, and another in Cassiopeia's Chair (fig. 10). One of these stars can be seen whenever Polaris is visible. The polar distance of Polaris is decreasing at the rate of 19″ a year. It also varies during the year by as much as 1′. The latter variation may be neglected, and the former also for a series of years.

Imagine Polaris to be the center of a clock dial, with the line joining 12 and 6 o'clock vertical and with the position of one of the lines described considered as the hour hand of the clock. The distance in azimuth of Polaris from the true north may be taken from the following table:

TABLE VI.

23. **Table showing the azimuths of Polaris** in different positions with respect to the pole. Epoch 1911; polar distance 70′. Latitude 0° to 18° north. This table may be used until 1930.

Clock reading of—		Azimuth of Polaris.	Clock reading of—		Azimuth of Polaris.	Clock reading of—		Azi- of Polaris.
δ Cass.	Z Ursae Maj.		δ Cass.	Z Ursae Maj.		δ Cass.	Z Ursae Maj.	
		′			° ′			° ′
XII:30	VI:30	18	IIII:30	X:30	49	VIII	II	358 59
I	VII	35	V	XI	35	IX	III	358 50
I:30	VII:30	49	V:30	XI:30	18	X	IIII	358 59
II	VIII	61	VI:30	XII:30	359 42	X:30	IIII:30	359 11
III	IX	70	VII	I	359 25	XI	V	359 25
IIII	X	61	VII:30	I:30	359 11	XI:30	V:30	359 42

For higher latitudes add to the small azimuths or subtract from the large ones, as follows:

Lat. 19°–30°, $\frac{1}{10}$.
Lat. 31°–37°, $\frac{2}{10}$.
Lat. 38°–42°, $\frac{3}{10}$.
Lat. 43°–46°, $\frac{4}{10}$.
Lat. 47°–50°, $\frac{5}{10}$.
Lat. 51°–53°, $\frac{6}{10}$.
Lat. 56°–57°, $\frac{7}{10}$.
Lat. 58°–59°, $\frac{8}{10}$.
Lat. 60°–61°, $\frac{9}{10}$.

It is well to keep track of the position of Polaris by noting it frequently and taking the corresponding clock time. Then if on a cloudy night a glimpse of Polaris is had, the observation may be taken even though the other stars can not be seen.

24. **For practical details of the observation,** the following may serve as a guide: Select a clear space of level ground not too near buildings or any object which might cause local disturbance of the needle. Drive a picket, leaving its top smooth and level, about 18 inches above the ground. Six feet north of the picket suspend a plumb line from a point high enough so that Polaris, seen from the top of the picket, will be near the top of the line (fig. 11). The line should be hard and smooth, about $\frac{1}{10}$ inch diameter. The weight at the bottom of the line should hang in a vessel of water or in a hole dug in the ground to lessen its vibration. Drive a second picket in range with the first one and the plumb line a short distance north of the latter. Make a peep sight by punching a hole

about $\frac{1}{16}$ inch diameter in a piece of paper and hold it on the top of the first picket: adjust it so that the star is behind the plump line when looking through the peep. Note the position of one of the stars on the imaginary clock face at the moment the observation is taken. Mark the position of the peep on the top of the first picket, and lay a straightedge or stretch a line from that point touching the plumb line to the second picket. Place the north-and-south edge of the compass box against the line or straightedge and read the needle. Find the azimuth of the star at the time of observation from Table VI.

If the **az. of Polaris** (Table VI) and the **reading of the needle are both less** or **both greater** than 180°, their **diff.** is the **declination: east** if the **needle** reading **is less, west if it is greater.** If one of these quantities is **less** and the other **greater** than 180°, add 360° to the lesser and take the **diff.** which is the declination: **east** if after the addition is made the **needle reading is less, west** if it is **greater** than the tabulated az.

This method will give results true to within ½°.

25. **Distances** passed over are ordinarily measured by the stride of a man or a horse, or by the revolutions of a wheel. Distances not passed over are determined by intersection or are estimated.

Pacing on foot.—The length of a man's **pace** at a natural walk is about 30 inches, varying somewhat above and below. A **stride** equals two paces. Each sketcher must determine his own length of pace by walking several times over a known distance. An unnatural stride should never be taken. Knowing the length of a pace or step, the measurement of a distance is only a matter of counting steps. The counting may be done mentally, and with practice becomes a subconscious operation, leaving the attention free to take note of surrounding objects and conditions. The greatest danger is of dropping 100 paces. It is better to keep a tally of the hundreds. By use of a **pace tally** all danger of error is avoided.

On level ground careful pacing will give distances correct to 3 per cent or less. The normal length of pace decreases on slopes. The decrease varies with the slope and with the direction, whether ascending or descending. The following table gives the length of pace on slopes of 5° to 30°, corresponding to a normal pace on a level of 30.4 inches.

TABLE VII.

Slopes.	0°	5°	10°	15°	20°	25°	30°
Length of step ascending	30.4	27.5	24.4	22.1	19.7	17.8	15.0
Length of step descending	30.4	29.2	28.3	27.6	26.4	23.6	19.7

For the same person, the length of step usually decreases with fatigue. Sketchers should test their pace when fresh and when tired, and if there is an appreciable difference, use one length for the morning and the other length for the afternoon work.

26. A distance on a slope measured by foot pacing may be reduced to the correct horizontal distance for plotting on the map by the following table, which takes account of the decrease in length of pace, Table VII, and also of the reduction to the horizontal, Table XII. This table can be used only when the length of pace has been determined on level ground, which should usually be done. When a considerable stretch of road is found with fairly uniform slopes, a special average rating may be made over a distance involving a fairly representative range of slopes and this *average rating* may be used without reduction.

TABLE VIII.

Number of paces measured on the slope.	Equivalent number of paces on horizontal, for slopes of—											
	5°		10°		15°		20°		25°		30°	
	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.	Up.	Down.
100	090.4	095.6	078.7	091.5	069.3	087.4	058.8	080.8	049.1	068.2	035.8	051.4
110	099.4	105.0	086.6	101.0	076.2	096.1	064.7	088.9	054.0	075.0	039.4	056.5
120	108.4	114.7	094.4	109.8	083.2	104.9	070.6	097.0	058.9	081.8	043.0	061.7
130	117.5	124.3	102.3	119.0	090.1	113.6	076.4	105.0	063.8	088.7	046.5	066.8
140	126.6	133.8	110.2	128.1	097.0	122.4	082.3	113.1	068.7	095.5	050.1	072.0
150	135.6	143.4	118.1	137.3	104.0	131.1	088.2	121.2	073.7	102.3	053.7	077.1
160	144.6	153.0	125.9	146.4	110.9	139.8	094.1	129.3	078.6	109.1	057.3	082.2
170	153.7	162.5	133.8	155.6	117.8	148.6	100.0	137.4	083.5	115.9	060.9	087.4
180	162.7	172.1	141.7	164.7	124.7	157.3	105.8	145.4	088.4	122.8	064.4	092.5
190	171.8	181.6	149.5	173.9	131.7	166.1	111.7	153.5	093.3	129.6	068.0	097.7
200	180.8	191.2	157.4	183.0	138.6	174.8	117.6	161.6	098.2	136.4	071.6	102.8
300	271.2	286.8	236.1	274.5	207.9	262.2	176.4	242.4	147.3	204.6	107.4	154.2
400	361.6	382.4	314.8	366.0	277.2	349.6	235.2	323.2	196.4	272.8	143.2	205.6
500	452.0	478.0	394.5	457.5	346.5	437.0	294.0	404.0	245.5	341.0	179.0	257.0
600	542.4	573.6	472.2	549.0	415.8	524.4	352.8	484.8	294.6	409.2	214.8	308.4
700	632.8	669.2	550.9	640.5	485.1	611.8	411.6	565.6	343.7	477.4	250.6	359.8
800	723.2	764.8	629.6	732.0	554.4	699.2	470.4	646.4	392.8	545.6	286.4	411.2
900	813.6	860.4	708.3	823.5	623.7	786.6	529.2	727.2	441.9	613.8	322.2	462.6

[illegible] distances [illegible]

[illegible] pace [illegible] taken [illegible] taken [illegible] hasty [illegible]

[illegible] their unit. [illegible] will give

[illegible] make an [illegible] distances

[illegible] for each distance.—If [illegible] miles and [illegible]. This [illegible] not be

[illegible] at a trot or [illegible] multiplying by 2

[illegible] for recording the number of [illegible] is in a leather case, 4½ [illegible] and 8). It is attached [illegible] To read, the case is [illegible] and the number of revolu- [illegible] the diameter of the wheel by [illegible] multiply the circumference by the num- [illegible] traveled by the wagon.

[illegible] kept free from grit and may [illegible] oils or grease must not be used. If good oil is not to be had, rub the bearings with a soft lead pencil.

Odometer readings are valuable as a rough check on a day's march. They are not accurate, but are free from large errors. Two instruments on the same wagon will not always agree. On heavy roads, mud or sand, there is a slip, sometimes positive and sometimes negative.

TABLE IX.

32. **Number of revolutions** per mile, of **odometers** attached to wheels 36 inches to 48 inches diameter:

Diameter of wheel.	Revolutions.
36 inches	560.2
37 inches	545.1
38 inches	530.7
39 inches	517.1
40 inches	504.2
41 inches	491.1
42 inches	480.2
43 inches	469.0
44 inches	458.4
45 inches	448.2
46 inches	438.4
47 inches	429.1
48 inches	420.2

Size of wheels of some military wagons: Ambulance, 36½ inches; ponton (light) tool and chess, 42⅝ inches; escort, 44¾ inches; ponton (heavy), 45 inches; Army six, 47⅛ inches.

33. **Estimation of distances** is a knack which may be cultivated by practice to a degree of accuracy far beyond that which is at first attainable, and quite sufficient for the location of many objects off the traverse line. Short distances are more closely estimated than longer ones; those on a level, than those up or down hill. When the intermediate ground can be seen, the estimation will be closer than when it can not.

A *rough estimate* of distance may be made from the velocity of sound, as by knowing the time that elapses between seeing and hearing the discharge of a gun, or the fall of an ax. Note the time in seconds and multiply by 400 for the distance in yards.

Distances across water are usually underestimated. The distance of the visible horizon on water in *miles* is $1.225 \sqrt{H}$; H being the height of the observer above the water surface in feet.

A cartridge or other small heavy object fastened to a string 10 inches long and allowed to swing throught a small angle or arc will beat half seconds approximately.

34. **The location of a point by intersection** is done by taking azimuths to it from two known points. As each of these azimuths when plotted must pass through the unknown point, it must be at their intersection.

An observer at an unknown point may locate himself from two visible known points by taking an azimuth to each. From the known points plot the corresponding *back azimuths* and they will intersect at the point of observation. This process is called **resection.** It is subject to errors of local attraction. (Par. 9.)

The accuracy of a location by intersection is affected by the relation of the azimuths and of the distances. The greatest accuracy results when the azimuths differ by 90° or 270° and the distances are equal; in which case the two azimuths and the base form a right-angled triangle. A difference of azimuths of less than 30° or more than 330° should be avoided.

Errors in length of the base, or distance between the known points, affect *the distances* in the same proportion. If the base is 5 *or 10 per cent in* error, both the distances will be in error in the *same direction* by the same percentage.

Distances are most easily determined from intersections by plotting the points and scaling. The distances are horizontal. If gradients are taken at the same points as the azimuths or at one of them, the elevation of the unknown point may be determined after the distance has been scaled.

35. **Tape chains** are adapted for the accurate measurement of considerable distances. The tape chain is a steel tape detachable from the reel on which it is carried, and with a handle at each end. It is graduated in feet, the last foot to tenths and the last tenth to hundredths.

Metallic tapes are of linen with wires woven in longitudinally. They are graduated in the same way as tape chains, and also in feet, inches, and eighths. Metallic tapes are used for the exact measurement of short distances, as dimensions of buildings, lengths of bridges, etc. They stretch slightly, but not enough to introduce appreciable error.

In **using tapes note carefully** whether the small divisions are inches or tenths of feet. See that the **first graduation** is the **proper distance** from the end, and if the tape has been spliced note whether the graduations on either side of the splice are the right distance apart.

Rules are used for measuring short distances and dimensions and are usually graduated in feet, inches, and sixteenths (fig. 45).

Rules approximately correct may be improvised in several ways. If a rule or rod graduated to feet be grasped in both hands, palms down, with the outside edges of the hands at consecutive foot marks and the thumbs extended toward each other along the rule, the tips of the thumbs will meet or pass, and by carefully noting their relative positions a foot may be approximately reproduced at any time by grasping a stick in the hands, placing the thumbs in the proper position, and marking the outside of the hands. A length may be measured in feet by passing along it hand over hand, placing first the edges of the hands together and then the thumbs as described.

Every military topographer should know the length of his shoe, his exact height, and the length of his forefinger. A copper cent is ¾ inch in diameter.

It is impracticable to adopt and adhere to one system of graduation. The decimal system is most convenient for computation. For field measurements an observer will make fewer mistakes with the system he is familiar with and should be allowed to use it.

The following table will convert units of one system into those of the other:

TABLE X.

36. **Table for conversion** of **inches** and **sixteenths** into decimals of a foot and the reverse. The quantities in the table are thousandths of a foot. The decimal point is omitted.

Ins.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
0	000	005	010	016	021	026	031	036	042	047	052	057	062	068	073	078
1	083	089	094	099	104	109	115	120	125	130	135	141	146	151	156	162
2	167	172	177	182	188	193	198	203	208	214	219	224	229	234	240	245
3	250	255	260	265	271	276	281	286	292	297	302	307	313	318	323	328
4	333	339	344	349	354	359	365	370	375	380	385	391	396	401	406	412
5	417	422	427	432	438	443	448	453	458	464	469	474	479	484	490	495
6	500	505	510	516	521	526	531	536	542	547	552	557	562	568	573	578
7	583	589	594	599	604	609	615	620	625	630	635	641	646	651	656	662
8	667	672	677	682	688	693	698	703	708	714	719	724	729	734	740	745
		755	760	766	771	776	781	787	792	797	802	807	813	818	823	828
		839	844	849	854	859	865	870	875	880	885	891	896	901	906	912
		922	927	932	938	943	948	953	958	964	969	974	979	984	990	995

TABLE XI.

37. 16ths of an inch in decimals of an inch:

$\frac{1}{16}$	$\frac{2}{16}$	$\frac{3}{16}$	$\frac{4}{16}$	$\frac{5}{16}$	$\frac{6}{16}$	$\frac{7}{16}$	$\frac{8}{16}$	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{11}{16}$	$\frac{12}{16}$	$\frac{13}{16}$	$\frac{14}{16}$	$\frac{15}{16}$
063	125	188	250	313	375	438	500	563	625	688	750	813	875	938

38. **Reduction to the horizontal.**—Distances measured along a slope may require a correction before plotting them on a map, as all map distances are, or are supposed to be, measured in a horizontal plane. Such corrections, when made, are called **reduction to the horizontal.** The following table gives horizontal distances corresponding to sloping distances for gradients up to 30°. This table is to be used in the same way as Tables II and III. The correction for slopes of 6° and less is too small to be plotted on the customary scales and is usually neglected. In flat or ordinary rolling country the correction will rarely be necessary.

TABLE XII.

39. **Horizontal distances** for gradients of 0° to 30° corresponding to distances on the slope:

Gradient in degrees.	Horizontal distances for sloping distances of—								
	1	2	3	4	5	6	7	8	9
1	09998	19997	29995	39994	49992	59991	69989	79988	89980
2	09994	19988	29982	39976	49969	59963	69957	79951	89945
3	09986	19972	29959	39945	49981	59918	69904	79890	89877
4	09976	19951	29927	39902	49878	59854	69829	79805	89781
5	09962	19924	29886	39848	49810	59772	69733	79695	89657
6	09945	19890	29836	39781	49726	59671	69616	79562	89507
7	09925	19851	29776	39702	49627	59553	69478	79404	89329
8	09903	19805	29708	39611	49513	59416	69319	79221	89124
9	09877	19754	29631	39507	49384	59261	69138	79015	88892
10	09848	19696	29544	39392	49240	59088	68936	78785	88633
12	09781	19563	29344	39126	48907	58689	68470	78252	88033
14	09703	19406	29108	38812	48515	58218	67921	77624	87326
16	09613	19225	28838	38450	48063	57676	67288	76901	86513
18	09510	19021	28532	38042	47553	57063	66574	76084	85595
20	09397	18794	28191	37588	46985	56381	65778	75175	84572
22	09272	18544	27815	37087	46359	55631	64903	74175	83446
24	09135	18271	27406	36542	45677	54813	63948	73084	82219
25	09063	18126	27189	36252	45315	54378	63441	72505	81568
26	08988	17976	26964	35952	44940	53928	62915	71903	80891
27	08910	17820	26730	35640	44550	53460	62370	71280	80190
28	08829	17659	26488	35318	44147	52977	61806	70636	79465
29	08746	17492	26238	34985	43731	52477	61223	69969	78716
30	08660	17320	25981	34641	43301	51961	60622	69282	77942

The horizontal distance corresponding to *any* sloping distance, and *any angle or gradient* may be found by multiplying the sloping distance *by the* **cosine** of the angle, Table XIV.

40. The **protractor** is an angular scale of equal parts used for plotting azimuths. That adopted for reconnaissance is the rectangular form (figs. 12 and 13). It is graduated on one face, which will be called the A face (fig. 12) from 0° to 180°, and on the other, or B face (fig. 13) from 180° to 360°. The graduation is clockwise on both faces. It has a scale of inches and tenths along one edge. The protractor may be used as ruler, scale, triangle, and parallel ruler.

To plot a given azimuth from a given point, draw a meridian through the point. If the azimuth is less than 180°, lay the protractor down A face up with the center at the point and the edge on the meridian, 0° to the north. Make a pencil dot on the paper at the proper graduation on the edge of the protractor. Move the protractor so that one of its edges passes through the two points and draw a line, which will be the desired azimuth.

If the azimuth is more than 180°, lay the protractor down B face up, 360° to the north, and proceed as before. The moving of the protractor after setting off the angle and before drawing the line may be avoided by adding a **counter-clockwise** graduation to the protractor. The sum of the two graduations at any point will be 180°. Place the center of the protractor and the given azimuth, read on the **counter-clockwise** graduation, on a meridian, and slide the protractor up or down, keeping the two points on the meridian until one of the long edges passes through the given point, when the azimuth may be drawn along that edge.

A semicircular protractor is shown in figure 14. It is usually double graduated, in opposite directions from 0° to 180°. With this form an azimuth may be laid off and the line drawn along the diameter without moving the protractor. Lay the protractor down with the center on a meridian. If the azimuth is less than 180°, place its number of degrees on the **counter-clockwise** scale on the meridian north of the center (fig. 15). If it is greater than 180°, subtract its number of degrees from 360 and place the difference on the **clockwise** scale over the north end of the meridian (fig. 16). In either case slide the protractor up or down, keeping the center and the graduation on the meridian until the diameter passes through the point, when the azimuth may be drawn along the diameter of the protractor. Figure 17 shows a triangle graduated for use as a protractor.

41. **Improvised protractors.**—If a rule is at hand, a protractor may be made as described for slope board in paragraph 14 by extending the 1° graduations around a half or whole circle. **If without compasses,** measure off the radius on a piece of paper, stick a pin through one extremity for a center and a fine pencil point through the other extremity and sweep the circle.

If without a rule, fold a piece of paper carefully through the middle. The folded edge should be straight. Place the ends of the folded edge together and fold again. The two edges now make an angle of 90°. Fold again through the middle and the angle will be 45°. Now fold in three parts and the angle is 15°. Spread the paper out flat and the creases will represent radii of 15° intervals. These may be divided into three equal parts by the eye, and the protractor will then read to 5°.

The hour graduations of a watch are 30° apart, and the minutes 6°.

42. **The scale of a map** is the ratio between *dimensions on the map and the* corresponding *dimensions on the ground.* If the lengths on map and ground were expressed in the same unit, the scale ratio would always be expressed by the number of ground units corresponding to the map unit. If 1 inch (map) corresponds to 120,000 inches (ground), the *ratio,* or *scale,* is plainly 1÷120,000, or as usually described, 1 to 120,000. This fraction is called the **representative fraction,** and designated R. F. But ground distances are so much greater than map distances that they are ordinarily expressed in a larger unit, which makes the scale ratio less apparent. *If 1 inch (map)* equals 10,000 feet (ground), the scale is still 1 to

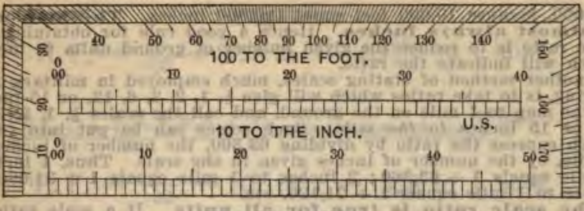


Fig. 12. A Face

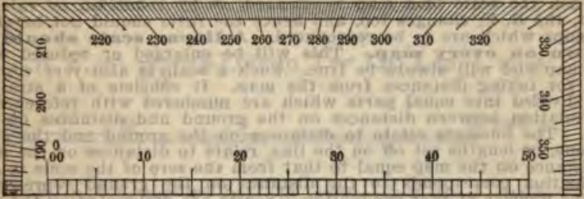


Fig. 13. B Face

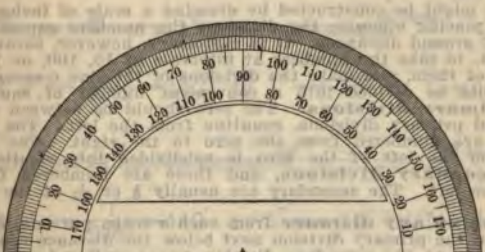


Fig. 14

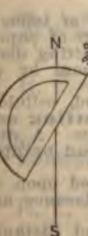


Fig. 15.

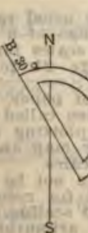


Fig. 16.

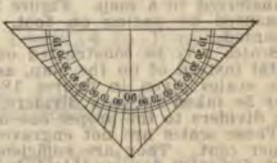


Fig. 17.

120,000, because 10,000 feet equal 120,000 inches. **The map unit is almost always inches.** Hence a good rule for obtaining the scale ratio is to reduce the given number of ground units to inches, which will indicate the ratio.

Another method of stating scales, much employed in military map making, is to take ratios which will give ½, 1, 2, 3, 6, 12, or 15 inches on the map to 1 mile on the ground, and call the scales ½, 1, 2, 3, 6, 12, or 15 inches *to the mile.* Such scales can be put into terms which express the ratio by dividing 63,360, the number of inches in 1 mile, by the number of inches given in the scale. Thus, 1 inch to 1 mile equals 1 ÷ 63,360; 2 inches to 1 mile equals 1 ÷ 31,680; 3 inches to 1 mile equals 1 ÷ 21,120, etc.

The scale ratio is true for all units. If a scale ratio is 1÷9,600, 1 inch (map)=9,600 inches (ground); 1 foot (map)= 9,600 feet (ground); 1 meter (map)=9,600 meters (ground), etc.

When the scale of a map is changed, as by reduction or enlargement, the R. F. changes too, and hence the ratio should not be given on maps which are to be reproduced. **A linear scale should be drawn on every map.** This will be enlarged or reduced with the map and will always be true. Such a scale is also very convenient for taking distances from the map. It consists of a straight-line divided into equal parts which are numbered with reference to the relation between distances on the ground and distances on the map. The numbers relate to distances on the ground and the graduations, or lengths set off on the line, relate to distances on the map. A distance on the map equal to that from the zero of the scale to any graduation corresponds to the distance on the ground represented by the number of that graduation. Scales are designated by the unit of their parts, as **scales of miles, scales of feet, scales of meters,** etc.

A scale might be constructed by drawing a scale of inches on the map and placing opposite the divisions the numbers expressing the equivalent ground distances. It is customary, however, because more convenient, to take the numbers at intervals of 10, 100, or 1,000, or multiples of them, and make the divisions of the line correspond. A scale should be divided into a convenient number of equal parts called **primary divisions.** The zero should be between the first and second primary divisions, counting from the left. The primary divisions are numbered from the zero to the right. The primary division on the left of the zero is subdivided into smaller parts, called **secondary divisions,** and these are numbered from the zero to the left. The secondary are usually ⅕ or ⅒ of the primary divisions.

To take off any distance from such a scale, put one leg of the dividers on the primary division next below the distance sought, and the other leg on the secondary division corresponding to the remaining figures.

Figures 18 and 19 give scales for the usual range of topographic maps, which may be taken off on the edge of a strip of paper and transferred to a map. Figure 20 gives scales for plotting distances measured by pacing on foot, and figure 21 for those by pacing mounted.

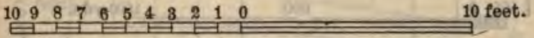
Scales may be constructed on strips of paper, wood, celluloid, or metal instead of on the map, and are then called **plotting scales.** The scales given in figures 18–21 are plotting scales. A distance may be taken between dividers from any map and read by applying the dividers to the proper one of these scales.

These scales are not engraved and can not be relied upon within 1 per cent. They are sufficiently exact for reconnaissance and, in fact, for most topographical drawing and scaling.

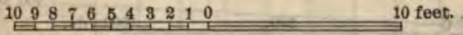
43. A series of points connected by azimuths and distances is called a **traverse,** *and the operation of determining the azimuths and distances is called* **traversing.** The latter term is usually

Fig. 18

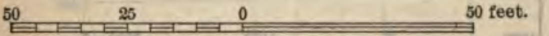
$R.\ F. = \frac{1}{100} = 8'.33$ to $1'' = 633''.6$ to 1 mile.



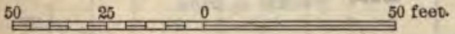
$R.\ F. = \frac{1}{120} = 10'$ to $1'' = 528''$ to 1 mile.



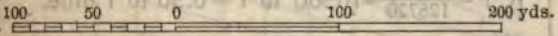
$R.\ F. = \frac{1}{500} = 41'.66$ to $1'' = 126''.7$ to 1 mile.



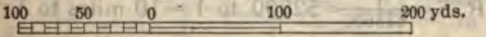
$R.\ F. = \frac{1}{600} = 50'$ to $1'' = 105''.6$ to 1 mile.



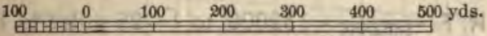
$R.\ F. = \frac{1}{4224} = 352'$ to $1'' = 15''$ to 1 mile.



$R.\ F. = \frac{1}{5280} = 440'$ to $1'' = 12''$ to 1 mile.



$R.\ F. = \frac{1}{10000} = 833'.3$ to $1'' = 6''.34$ to 1 mile.



$R.\ F. = \frac{1}{10560} = 880'$ to $1'' = 6''$ to 1 mile.

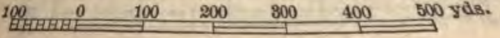
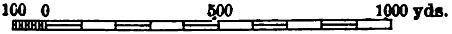
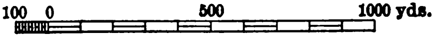


Fig. 19

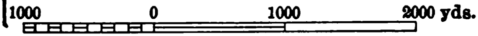
R. F. $=\frac{1}{20000}=1666'.7$ to $1''=3''.17$ to 1 mile.



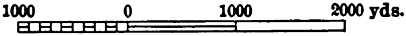
R. F. $=\frac{1}{21120}=1760'$ to $1''=3''.00$ to 1 mile.



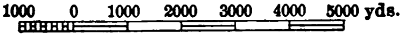
R. F. $=\frac{1}{52800}=4400'$ to $1''=1''.2$ to 1 mile.



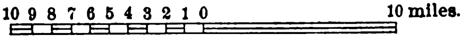
R. F. $=\frac{1}{63360}=5280'$ to $1''=1''.00$ to 1 mile.



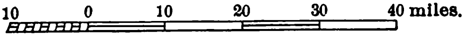
R. F. $=\frac{1}{126720}=10560'$ to $1''=0''.50$ to 1 mile.



R. F. $=\frac{1}{633600}=52800'$ to $1''=10$ miles to $1''$.



R. F. $=\frac{1}{1584000}=132000'$ to $1''=25$ miles to $1''$.



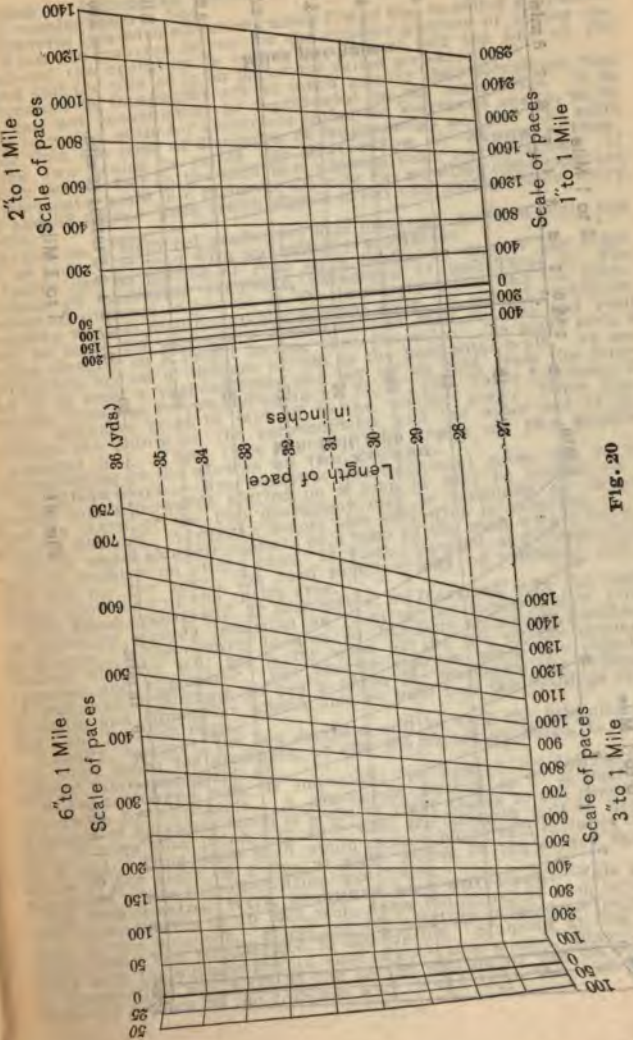

2" to 1 Mile
Scale of paces
2000
1600
Scale of paces
1" to 1 Mile
36 (yds)
Length of pace
in inches
6" to 1 Mile
Scale of paces
1500
Scale of paces
3" to 1 Mile

Fig. 20

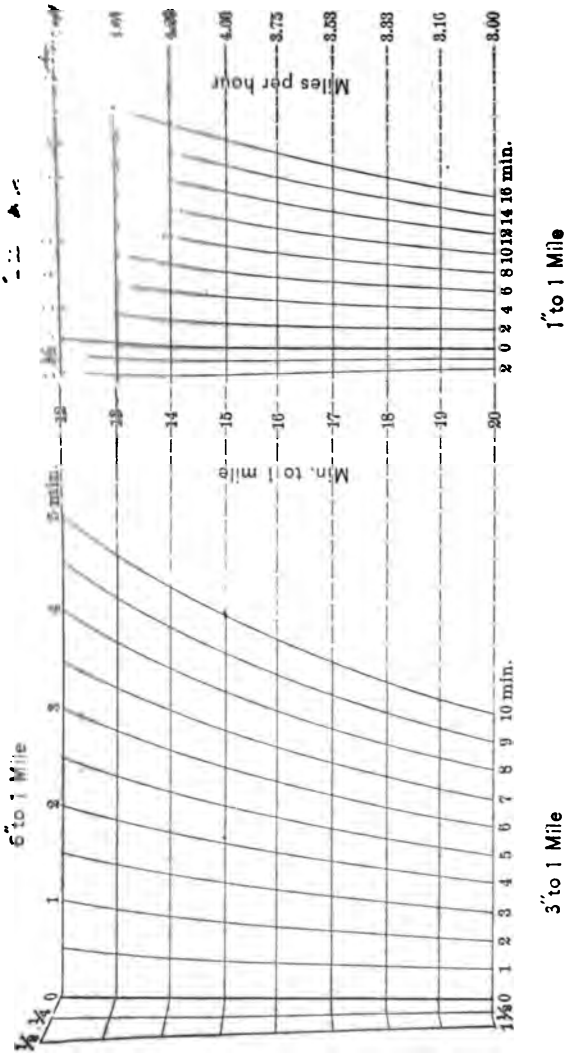

6" to 1 Mile
1" to 1 Mile
3" to 1 Mile
Miles per hour
Min. to 1 mile
5.00
4.61
4.28
4.00
3.75
3.53
3.33
3.16
3.00
12
13
14
15
16
17
18
19
20
2 0 2 4 6 8 10 12 14 16 min.
0 1 2 3 4 5 6 7 8 9 10 min.
0 1 2 3 4 5 min.
¼
½
20 min.

Fig. 21

extended to include all azimuths, distances, and elevations taken while running such a line.

A traverse line with elevations along it may also be called a **profile,** and when the traverse is run for the express purpose of taking the elevations, the operation is called **profiling;** and the line on the ground and the plot of it on paper are called **profiles.**

Distances in topography are so much greater than elevations that both can not conveniently be represented on the same scale. It is usual to take a scale for elevations called the **vertical scale,** much larger than the scale of distances, or **horizontal scale.** The ratio of the two scales is called the **distortion** or **exaggeration.** Ten or twenty feet to the inch is a common scale for elevations. If the horizontal scale is 3 inches to the mile, the resulting distortions are 176 and 88 times. Both scales should always be written below every profile.

Angles on a distorted profile are also distorted, and gradients can not be plotted or read with an ordinary protractor.

Angles can be plotted or read on a profile by any of the other methods of expressing gradients, paragraph 11 and Table I. The horizontal distance is plotted to the horizontal scale and the corresponding vertical distance to the vertical scale. A special protractor may be made for any given distortion and used to plot and read angles directly on a profile having that distortion. To make such a protractor, lay off a distance of 100 to the horizontal scale. At one end of it erect a perpendicular and lay off on this, from the intersection, distances corresponding to 1°, 2°, 3°, etc., Table I, column 2. These distances must be laid off to the vertical scale. Draw lines through the points on the perpendicular and the other end of the horizontal line. These lines represent the angles **on the profile** corresponding to the **slopes on the ground.**

44. **Fieldwork.**—Measurements and additional notes may be recorded and afterwards plotted on a map or may be plotted on a map as taken or the two operations may be combined, as circumstances demand. A written report also will often be required.

45. **A road sketch** consists of a map of the road with a narrow belt of country on either side. If roads, parallel and intersecting, are not too far apart, the road sketches may be combined into a fairly good map of the entire area.

The **road itself** will, if practicable, be traversed with the degree of precision already indicated as required for topographical reconnaissance. If the country is open, so that long sights are possible, a trained observer will get better work by the use of the prismatic compass and clinometer. For shorter courses, when the object is of sufficient importance to use a chain for distances, the prismatic compass and clinometer should also be used and the readings taken with the greatest care.

Usually, however, the box compass will be used for azimuths and the slope board for gradients, or else the sketching board, to be described later, paragraph 55.

Side features will, if important, be located by intersection; otherwise by estimation. A convenient method is to estimate the distance of an object when it bears at right angles to the course and plot it from that point. In such case the azimuth will be denoted by R or L. Thus *house 300 R* would mean a house at a distance of 300 units to the right on a line at right angles to the course through the point where the observation was taken.

46. **Traversing with compass and notebook.**—Rule a column three-fourths of an inch wide down the center of each left-hand page of the notebook. Select for the starting point some object or point which can be identified by description. Standing at this point sight with the compass toward some object—tree, stump, telegraph pole, or stone—that will serve as the second station of the traverse line. Note *the reading of the* compass and record it in the center column

of the notebook at the bottom of the first left-hand page, making also the symbol for ⊙ 1. Observe and record also the azimuths of any other objects which are to be located from ⊙ 1. All the observations taken at this station are written in order in the central column from the bottom upward and are bracketed together with the station symbol. The name of each object is written on the same horizontal line with its azimuth—on the right side of the page if on the right of the traverse and on the left side of the page if on the left of the traverse. If elevations are to be obtained, observe the gradients from ⊙ 1 to the several objects and place each in the notebook next to the corresponding azimuth.

Proceed toward ⊙ 2, counting paces. Halt when necessary to sketch and measure offsets to objects on either side of the course, to take bearings of intersecting roads, paths, streams, etc. When a halt is made a mark is scored on the ground, the distance in paces from the last ⊙ recorded in the central column, and the desired notes made. Distances along the main line, azimuths, and gradient angles only are recorded in the central column. All descriptive matter relative to side objects is placed outside of that column on the side corresponding to that where the objects lie. Return to the scored mark and resume the pacing, beginning with the number recorded at the halt, so that the total count of paces at any point shall be the number taken since leaving the last ⊙.

The center column of the page is taken to represent the line actually paced and to be without width, so that offsets in the side sketches are shown measured from the sides of the column and not from its center.

On reaching the second ⊙, record its distance from ⊙ 1, draw a horizontal line across the page, write ⊙ 2 in the center column above the line, and continue as before to ⊙ 3.

It is well at ⊙ 2 to take a back azimuth on ⊙ 1. This should differ from the azimuth of ⊙ 2 from ⊙ 1 by exactly 180°. A marked discrepancy indicates error in observation or the effect of local attraction on the needle, and should be investigated before proceeding. If a back azimuth is taken it should be the first observation made and recorded.

When opportunity offers, take bearings on distant bends of the road, spires, towers, hilltops, tall trees, etc., and enter the angles in the center column with the name of each object written beside its bearing. Endeavor to get bearings of the same distant object from several stations or from two stations at some distance apart. These, when plotted, should intersect at a common point if the observed bearings are correct and the compass has not suffered local disturbance. It is not to be expected in work of this grade that an exact intersection of more than two bearings can be obtained except by accident.

When a sketcher at any point of the traverse finds himself in prolongation of a line that defines or bounds a feature of the country, such as a fence, the edge of a wood, a reach of shore line of river or lake, a gully, canyon, or ridge, a face of a building, or a stretch of road or railroad, its bearing should be taken. The same rule should be observed when important features come into range with each other from a point on the traverse. A valuable check on the relative positions of such features is thus obtained.

If a traverse line is interrupted by any obstacle that interferes with the measurement of distance, its width should be estimated and the pacing resumed on the other side; or, for greater exactness, make an offset, perpendicular to the traverse line if possible, long enough to clear the obstacle, continue the traverse parallel to the original course, and return to the latter after passing the obstacle by a second offset parallel and equal to the first and in the opposite direction; or, locate points on the farther side by intersections.

47. **The unit of measure should be clearly stated in the notes.** Ordinarily distances along the course are in paces, while estimated offsets may be in paces, feet, yards, or fractions of a mile, according to their distances, and also according to the unit in which the sketcher finds he can make the closest estimate.

On the usual reconnaissance scales the dimensions of buildings, width of roads, bridges, etc., can not be plotted to scale. They are shown exaggerated, and the true dimensions, if important, must be given in figures.

48. **The best method of plotting** is to plot the traverse lines and the check bearings first. Then any error discovered by means of the latter, or by closure on the initial or other known point can be more readily corrected. When the traverse line has been adjusted, the details on either side are plotted in and do not have to be changed.

The outfit desirable for the method of traversing with compass and notebook is the following: Notebook or sheets of paper ruled as described, prismatic or pocket compass, pencil of medium hardness, rubber eraser, pocket knife, 25-foot tape, a piece of twine 100 feet long. The absolute necessities are the paper, the compass, pocket knife or pencil sharpener, and rubber-tipped pencil. The tape measure is to be used for making small measurements of distance or dimensions. The cord is useful for measuring depths of water, heights of structures, etc. It should be graduated to yards by knots.

49. **The topographic field notebook** is designed to facilitate the foregoing method of traversing. In addition to the central column, it has columns on either side in which to record the offset distances, each of which is put down on the proper side of the central column, avoiding the necessity of using the letters R and L, and eliminating the liability of mistakes in confusion of the direction.

The opposite right-hand page is ruled in 1-inch squares, and has a full-circle protractor graduated to degrees printed on it. This page facilitates a hasty plot of the traverse with respect to which many details can be sketched in more clearly and certainly than they could be recorded in writing. At the bottom of the page are scales of tenths and eighths of inches. The alternate pairs of pages are plain ruled for notes and memoranda. Figures 22 and 23 show the arrangement and illustrate the use of the book described.

50. **Traversing with compass and drawing board.**—The observations are taken as in traversing with a notebook and compass, but the traverse line and such offsets as come within the limits of the sketch are plotted at once; that is, the map is drawn as the observer proceeds over the ground. A great advantage of this method is that any large error in measurement is likely to be detected by the eye, as the map is compared with the ground, and errors can be corrected on the spot. The plotting scale of equal parts should be prepared beforehand to suit the scale of the map. If this scale can be pasted or drawn on the edge of the protractor opposite the angular graduation, it is a convenience.

The sides of the sheet of paper should be letered N, E, S, and W to correspond with the points of the compass. If the paper is ruled or water-lined, the lines are taken parallel to the magnetic meridian.

Having observed the azimuth at ⊙ 1, draw through the point designating that station a line having the observed azimuth. Azimuth lines are erased finally as a rule, and hence should be lightly drawn and with a fairly hard pencil. Prolong this line in the direction of ⊙ 2 far enough to surely reach that ⊙. If other azimuths are taken at ⊙ 1, plot them also, and note on each the object to which it bears. If the distance to the object is estimated, it may be laid off on the azimuth and the position of the object plotted at once.

Proceeding toward ⊙ 2 to take any desired side shot, halt abreast of the object, plot the distance from ⊙ 1 on the course, estimate the distance to the object, and plot it in at that distance opposite the point plotted on the course and on the proper side.

Arrived at ⊙ 2, lay off the entire distance from ⊙ 1, and plot and mark ⊙ 2. Erase the azimuth line beyond ⊙ 2; take and plot any other desired azimuths. If any of them are to points previously sighted to, make the intersections and plot and mark the points. In plotting azimuths to side objects, it is better to draw only a short part of the line near the object to avoid confusion of lines on the sketch and especially near the station.

Remarks Left.	Offsets Left.	Courses & Distances	Offsets Right.	Remarks Right.
Crossed wagon road		1230	230	Road running N.& S.
running E.& W.		4° R.		through Alpine
Crossed dry Cr.		880		village.
Cr.	12	100	230	Farm H.
Cult.		18°00′		
		⊙5		
		3256		
		$7^h 41^m$		
R.R.Br.	100	4000		
Cr.	25	3080		Crossed dry Cr.
		2765		Crossed wagon road
Cr.	2	2465		Crossed dry Cr.
R. R. Br.	100	2300		
R. R Br.	250	1760		
		1660	200	Farm H.
		1650		Crossed Wagon road
				running E. & W.
Creek 30 wide	440	620		
Woods along Cr.				
		34°00′		
Rolling Prairie		⊙4		Pasture
Pasture		1230		
		$7^h 4^m$		
Farm H.	110	800		
Farm H.	150	600		
		450		Crossed wagon road.
		230	160	Farm H.
		1.5° R.		
		303°00′		
Corn & Wheat		⊙3		Corn & Wheat
		1530		
		$6^h 50^m$		
		1230		Crossed Cr. 15 wide.
Creek, dry run	130	880	175	Farm H.
		3° F.		
		343°00′		
		⊙2	50	Farm H.
Left wagon road		230		Cult.
Cult.		$6^h 33^m$		
Farm H.	25	200		Level Country
		100	10	Farm H.
Left Mokena $6^h 30^m$ A.M.		0°00′		Following wagon road.

Sept. 4th, 1900.

$6^h 30^m$

⊙1

All distances in Yds.

Beginning

Fig. 22

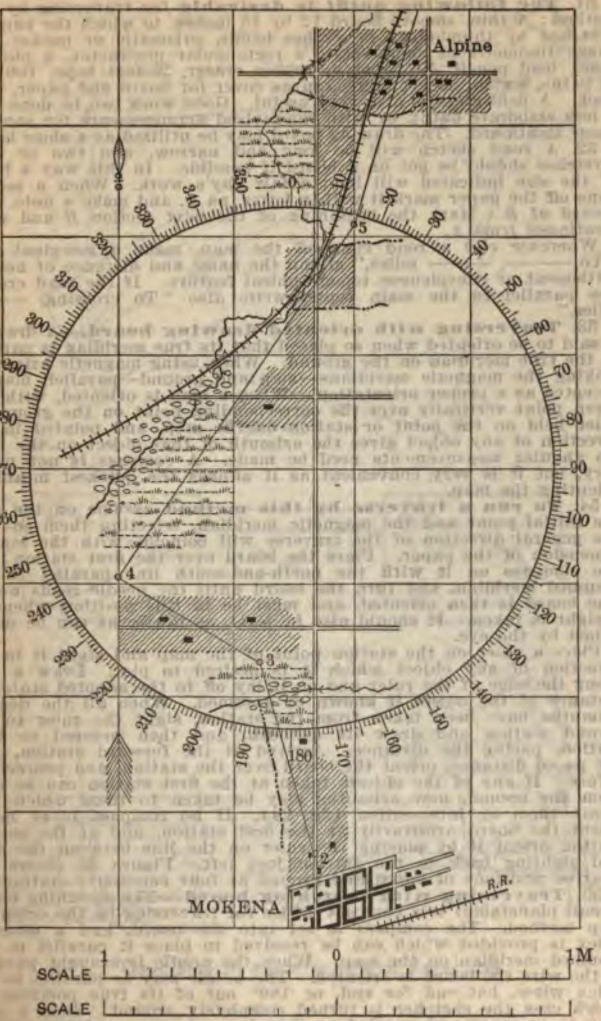

Alpine
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
5
4
3
2
R.R.
MOKENA
SCALE
1
0
1M
SCALE

Fig. 23

51. **The following outfit is desirable** for traversing by this method: A thin, smooth board 12 by 15 inches, to which the paper is attached by thumbtacks or rubber bands, prismatic or pocket compass, clinometer or slope board, a rectangular protractor, a plotting scale, lead pencil, No. 3 or 4, rubber eraser, 25-foot tape, 100 feet of twine, watch, pocket knife, canvas cover for board and paper, notebook. A field glass is also very useful. Good work can be done with a less elaborate outfit, or with improvised arrangements for some of those mentioned. The drawing board may be utilized as a slope board.

52. A road sketch will be long and narrow, and two or more stretches should be got on a board if possible. In this way a board of the size indicated will hold a fair day's work. When a section runs off the paper mark it with a letter, as *A*, and make a note, *Continued at B*. Mark the beginning of the next section *B* and write *Continued from A*.

Wherever else a road runs off the map, make a marginal note "To —— ——, ——— miles," giving the name and distance of nearest settlement or conspicuous topographical feature. If the road crosses one parallel to the main route, write also "To crossing, ——— miles."

53. **Traversing with oriented drawing board.**—A drawing is said to be oriented when so placed that its true meridian is parallel to the true meridian on the ground. When using magnetic azimuths, making the magnetic meridians—map and ground—parallel, may be accepted as a proper orientation. When a map is oriented, with any given point vertically over the corresponding point on the ground, a ruler held on the point or station on the map, and pointed in the direction of any object gives the azimuth of that object on the map. No angular measurements need be made. A compass is not necessary, but it is very convenient as it affords the quickest means of orienting the map.

54. **To run a traverse by this method** assume on the map the initial point and the magnetic meridian, selecting them so that the general direction of the traverse will coincide with the longest dimension of the paper. Place the board over the first station; lay the compass on it with the north-and-south line parallel to the assumed meridian, and turn the board until the needle reads north. The board is then oriented, and must be in this position whenever a sight is taken. It should also be level, as nearly as can be determined by the eye.

Place a ruler on the station point of the map and sight it in the direction of any object which it is desired to plot. Draw a line along the edge of the ruler and on it lay off to the adopted scale the distance of the object if known or assumed. When all the desired azimuths have been taken from the station, sight the ruler to the second station and draw its azimuth, and then proceed to that station, pacing the distance. Arrived at the forward station, plot the paced distance, orient the board over the station, and proceed as before. If any of the objects taken at the first station can be seen from the second, new azimuths may be taken to them which will locate them by intersection (fig. 24). If no compass is at hand, orient the board arbitrarily at the first station, and at the second station orient it by placing the ruler on the line between the two, and sighting back to the station just left. Figure 25 shows the relative positions of board and ground at four successive stations.

55. **Traversing with sketching board.** The sketching board [illegible] is a compact device for traversing by the oriented-board method. The compass is set into the board, and a movable [illegible] parallel to the assumed [illegible] When [illegible] parallel [illegible] the board is oriented. [illegible] in [illegible] is turned completely around. Such a mis- [illegible] a [illegible] at the outset whether the N or S end of the

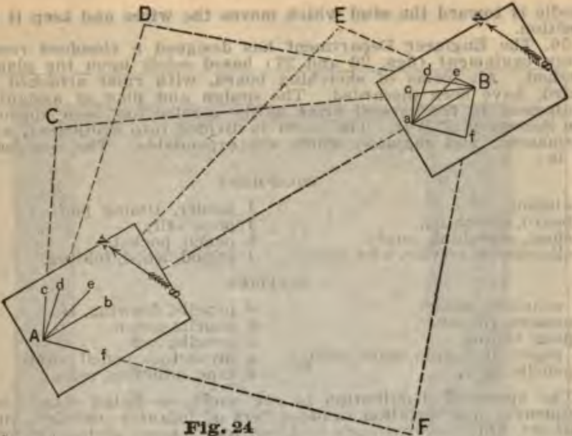


Fig. 24

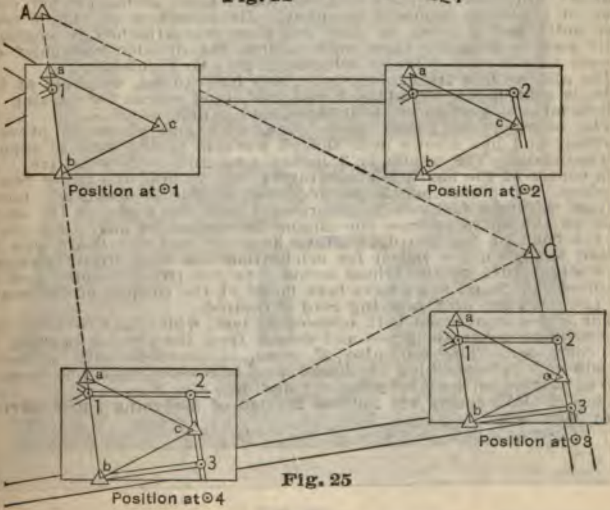


Fig. 25

Traversing by plane table and Resection

needle is toward the stud which moves the wires and keep it in this position.

56. The Engineer Department has designed a *standard reconnaissance equipment* (figs. 26 and 27) based solely upon the plane-table method. All forms of sketching board, with ruler attached to the board, have been discarded. The design and plan of assigning the equipment to the several arms of the service has been approved by the Secretary of War. The outfit is divided into *equipment,* which is permanent, and *supplies,* which are expendable. The complete outfit is:

EQUIPMENT.

1 alidade.
1 board, sketching.
1 chest, sketching outfit.
1 clinometer, service, with case.
1 holder, timing pad.
1 pace tally.
1 pencil pocket.
1 tripod, wood, folding.

SUPPLIES.

12 celluloid, sheets.
2 erasers, rubber.
6 pads, timing.
72 paper, sketching board, sheets.
2 pencils, blue.
6 pencils, drawing, H.
2 pencils, green.
2 pencils, red.
2 protectors, pencil point.
2 tape, adhesive, rolls.

The approved distribution is one outfit, as listed above, to each regimental and battalion headquarters of infantry, cavalry, and field artillery, and three to each engineer tool wagon, giving six per company or three per mounted company. Headquarters of higher engineer units and division or chief engineers not attached to engineer units receive normally three such outfits, but division and chief engineers may receive a larger number if they so requisition.

The alidade is a triangular scale, $10\frac{3}{16}$ inches long, weighted at the ends, is conveniently graduated and has blank spaces for pasting on individual scales of paces, walk, trot, and gallop.

The board is of $\frac{5}{8}$-inch white pine, with end pieces to prevent warping, and has screws over slotted washers in the ends to permit of expansion. The needle is 3 inches long and quite sensitive. At each corner of the board is a substantial clip to hold the paper firmly in place. No plumb bob is provided, but a hole is accurately bored so that a plumb bob can be improvised and use made of the slope scale on the board in case the clinometer should be lost. The plate on the back of the board is let in flush so that the board can be turned freely on the tripod for orientation and then firmly clamped by a slight turn of the tripod screw. As the tripod is not used in mounted sketching, holes have been bored at the corners of the board for the insertion of a carrying cord if desired.

The tripod is of wood with telescoping legs, which fold to 15 inches or extend to about 40 inches and detach from the top for packing in the container. The top, also of wood, is provided with a heavy thumbscrew for attaching the board, and is covered with felt to give a firm bearing without sticking or binding.

The celluloid sheets are for use instead of sketching paper during rainy weather.

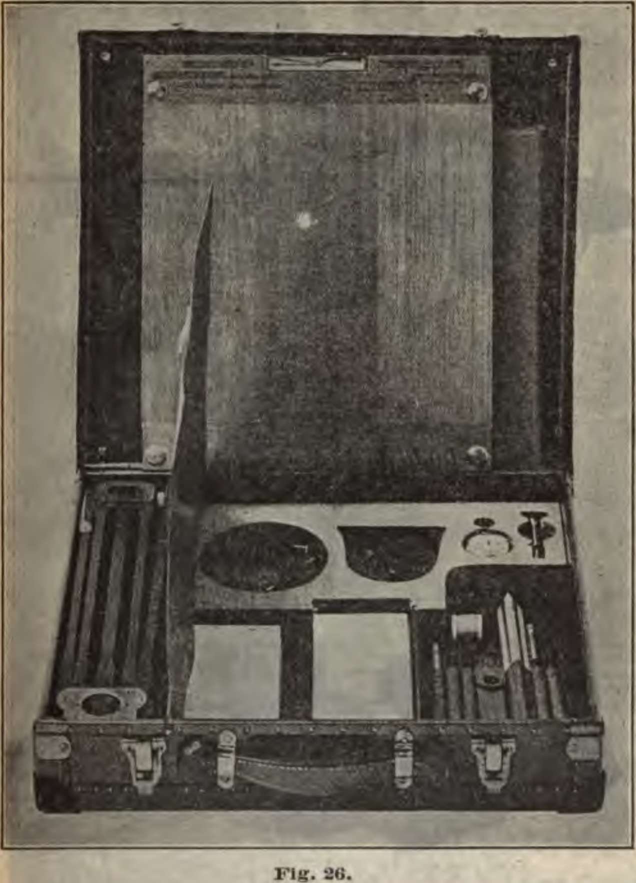


Fig. 26.

57. A road reconnaissance should procure data on the following subjects:

The road.—Gradients, especially the steepest; width of roadway; if paved, width, kind, and condition of paving; width and depth of side ditches, and whether wet or dry; if not paved, character of soil, sand, clay, or gravel; kind of fences and width between them. The sketch should also show where the road is in embankment or cutting; where wagons can not double or pass, and where foot troops can not march along the side between the wagon track and the fences.

Bridges.—Material of piers and abutments; type and material of superstructure, as girder, truss, arch, suspension, wood, steel, stone, etc.; width of roadway, and clear headroom; safe load (see Bridges). Of bridges over the road, clear width and height; over streams, the nearest bridges above and below and whatever information can be obtained about them.

The country.—Character of cultivation or natural vegetation; areas and density of timber, underbrush, vines, especially poisonous ones; marshes and fords, kinds of fences, nature of soil; general configuration of surface, especially high hills, long ridges or valleys, bluffs or slopes too steep to scale, and practicable routes to their crests.

Streams crossed.—Name, width, depth, and surface velocity in swiftest current; velocity noted as sluggish, moderate, quick, or swift; elevation of high-water marks in relation to the road; which bank is the higher at crossing and above and below, and how much; accessibility of water for stock; fords at or near crossing; length, depth, and steepness of approaches; levees or embankments, height, and thickness on top; if navigable, to what distance above and below and for what class of vessels—steamers, flatboats, rowboats.

Towns and villages passed through.—Name, location on map, and population. Names of streets to be traversed. Material, as stone, brick, frame, log; size, 1, 2, 3 stories, and distribution, close or scattered, of the houses in those streets; gradients of intersecting streets; location of railway depots, post, telegraph, and telephone offices; of drinking fountains and watering troughs; of elevators, storehouses, or other accumulations of food or forage; of blacksmith, wagon, and machine shops.

When ordered to make a complete examination of a town or village note besides the foregoing, location and size of principal buildings, halls, court and school houses, churches, banks, jails, and their ownership; sources, maximum quantity and distribution of water supply; sanitary conditions and disposal of wastes; location of railroads, depots, freight houses, sidings, etc.; for all roads entering from the surrounding country the same information as scheduled above for streets; location and extent of open spaces, and of large substantial buildings standing apart; location and extent of high ground within range, especially that from which streets can be enfiladed.

Railroads crossed.—Name, gauge, single or double track, sidings and loading platforms at point of crossing; crossing at grade, over or under; distance and name of nearest station each way; direction and distance of nearest roundhouse, shops, etc.

58. **River reconnaissance.**—Designate the banks as right or left, the right bank being that on the right hand when looking down the stream. If, when standing on the bank facing across the stream, the current flows from left to right, the observer is on the right bank; if from right to left, he is on the left bank.

If the stream is navigated, pilots and residents will know distances by channel between landings with sufficient accuracy for the purposes of a field reconnaissance. In making a traverse along the banks of the river, it may be desirable to cross from one side to the other to save distance or avoid obstacles. When a crossing is to be made, at two or three stations from the point of crossing select a point on the other side and take an azimuth to it. From the last station take another azimuth to the selected point, locating it by intersection. If the conditions prevent an intersection, take an azimuth from the last station to the point on the opposite bank and estimate the distance.

The valley.—General configuration, heights of limiting ranges, and positions of passes or roads crossing them; commanding ground from which a stretch of the channel of considerable length can be enfiladed by artillery; forest growth on or near banks; soil and cultivation of the valley; roads parallel to river, and means of access to them from the river.

The stream.—Its width, depth, and velocity; navigability, as for steamboats, flatboats, rowboats, rafts, and head of navigation for each; nature of obstructions to navigation and possibility of removing or avoiding them; season of high and low water; average rise and fall; rapidity of rise and fall, and causes; amount of drift; character of banks and relative command. Quality of water; amount and kind of sediment borne; usual period and thickness of ice.

Tributaries and canals.—Width, depth, navigability, and means of crossing. Nature and purpose of canals; dimensions and lifts of locks; time for lockages; means of destroying locks and effect of destruction; floating plant found.

Bridges and fords.—As in road report. Also for bridges note position of the channel and navigable width between piers; height of arches and lower chords above the water at different stages; dimensions and operation of draw spans. Note the exact position of fords and the marks on both banks by which they may be found; length, width, and nature of bottom; velocity of current; position of deep holes; aids to crossing. Fords should not be more than 4 feet 4 inches for cavalry, 3½ feet for infantry, and 2 feet 4 inches for guns and ammunition. Note nature of approaches to bridges and fords; width of roadway, slopes, soil, effect of weather and traffic. Note especially the defensibility of bridges and fords.

Ferries, boats, and other means of crossing.—Position of ferries; approaches and practicability for horses and loaded wagons; sizes, number, and kinds of boats; method of propulsion; sites for military bridges or ferries; character of site for construction, use, and defense; proximity of islands and tributary streams; approaches and slope of banks; width of river and maximum surface velocity of current; materials for the construction or repair of boats, bridges, or ferries.

Inundations.—Places suitable for inundations by damming or obstructing a narrow bridge span, or by cutting a levee or dike. Note raised roads on ground liable to natural or artificial inundations and the safest route to follow by known landmarks when the road is overflowed. An extensive inundation 2 feet deep on level ground is a serious obstacle unless the roads are very sound and marked by trees, posts, etc. Even when so marked a dip in the roadbed of 3 or 4 feet may render the road impassable. A railroad bed is soon washed out even by a slight overflow.

59. **Reconnaissance of a railroad.—The line.** Local name; terminal points and distances between stations and other points; gauge; single or double track; condition of roadbed, ties, and rails; drainage and liability to overflows or washouts; facilities for repair; condition of right of way for marching troops along the line.

Tunnels and bridges.—Number and location; dimensions; strength of bridges; means of destroying and repairing; of blocking traffic.

Rolling stock.—Number and nature of engines and cars available; capacity for transporting troops between given points; facilities for constructing armored trains, as spare rails, old boilers, etc.; location and capacity of shops and store yards.

Stations.—Name and location; facilities for entraining and detraining troops with wagons and horses; platforms on through line and sidings; ramps; sidetracks, number and capacity; turntables; water tanks; fuel supply; storage facilities; derricks or cranes; cross-overs for teams and pedestrians. Facilities at hand for hospitals, camps, depots; for feeding men, heating coffee, watering horses during temporary halts.

Other communications.—Telegraph lines; number and location of stations, number of wires; connections; parallel highways, roads, rivers, or canals; means of access from same to railroad; junctions and crossings of other lines; relative elevation; facilities for laying temporary switches and sidings at stations or between crossing lines.

Defensibility.—Heights commanding line of road; defense of stations; defense of road and telegraph lines against raiding parties; structures exposed to demolition; defense and attack of same; defiles and river crossings.

60. Reconnaissance of a wood or forest.—Note all roads and paths, and all hills, ravines, and streams within the wood or skirting the edges; kinds of trees, density and growth; underbrush, prevalence of poisonous shrubs and vines; marshy or large open spaces; practicability of forming new roads by cutting; creation of obstacles by felling trees; if there are no roads traverse the shortest practicable path between the point of entrance and point of exit, and mark bowlders or blaze trees, set stakes, or otherwise indicate this path, and also give compass bearings of the route to be followed. Note the exterior forms of the woods, whether parts of the edge flank other parts; connection with neighboring pieces of wood by scattered trees or clearings; undulations of the ground that would give cover to attacking force or to defenders.

61. Reconnaissance of mountains.—Note the number and positions of passes through the mountains, of roads and trails leading to these passes, their condition, practicability, and means of repair; steepness of slopes on the sides of roads; means of constructing additional roads; watercourses, their direction, nature, and time of floods; means of crossing. Note ravines and open glades on mountain sides, lookout points, and good signal stations; note time and duration of snowdrifts on roads or passes; depth of drifts and possibility of removing them or of traveling on the surface of the snow. Note extent and nature of forest growth.

62. Reconnaissance for a camp or winter quarters—Site.—Location, elevation, and area; sanitary features, such as drainage, dryness, and general character of top soil; proximity of swampy ground or stagnant ponds.

Communications.—Sufficiency of existing roads and paths, maximum grades, probable condition under heavy traffic and in bad weather, location and kind of materials available for improvement or repair, railroad or water communication and terminal facilities of same.

Water and fuel.—Location, kind, and quantity of fuel at hand; quality and quantity of water; facilities for filling water carts, for watering animals and for washing and bathing; nature of supply, as wells, springs, running streams, and its reliability.

Shelter and conveniences.—Proximity of trees, brush, wood, hay, and straw for huts and bedding; of markets; of towns and villages.

Defensibility.—Location of outposts and guards; location and character of defensive positions in or near the camp; force required to hold positions which may command the camp.

63. Reconnaissance of a position.—This problem usually includes the selection of the position, and is therefore tactical as well as topographical. Certain relations and conditions must be observed in the selection, and the extent and degree in which they are found must be *clearly shown on* the map or in the report.

The length of the positon, or its development along the firing *line, should be proportional to the force available for its occupation.*

Exact rules can not be given, but 5,000 infantry per mile or 3 men per yard is the usual estimate.

The **flanks must be secure.** Impassable natural features, a river, mountain, or stream form the best flank. Lacking these, a wood, a deep ravine, a cliff, or a high hill will serve. Even with these features absent a flank may be strengthened by the construction of a strong earthwork, but the general rule obtains that natural weakness of the flanks must be made up by a greater number of men, or by the substitution of cavalry for infantry in case the ground favors the movements of mounted troops.

If the **flanks are naturally strong** the line should be withdrawn to make the entire position reentrant; if the **flanks are naturally weak** the connecting line should be held straight or advanced so as to make the position straight or salient.

The **depth of the position,** or its extent in rear of the firing line, should afford natural cover for supports, reserves, and trains, which may require a total depth of 800 to 2,400 yards, but a short position may be relatively shallower than a long one. Three or four parallel ridges, 300 to 600 yards apart, with the intervening ground practicable, form an excellent position. If the first ridge is somewhat higher than the rest, so much the better. Whatever cover there may be for the component parts of the force, whether natural or artificial, fences, ditches, trees, etc., should be shown or described. If digging is necessary, its amount and the character of the soil should be stated.

Strong points in front of the line, which may be occupied as outposts, should be shown.

Communication should be free in every direction, concealed so far as possible from the enemy's view.

Artillery positions are required when that arm is represented in the occupying force, as will usually be the case. They should permit the guns to sweep all ground in front of the position over which the enemy can advance to the limit of effective range. Every point in front of the position and within range which commands any part of it is an element of weakness.

Ranges at which the enemy can be seen and reached by artillery fire; the points beyond rifle range covered by such fire and its relative command of adverse artillery positions should be shown or described.

If possible, similar information should be obtained of the ground likely to be occupied by the enemy in forming for attack or in taking up a counter position.

64. A **position occupied by an enemy** must be reconnoitered from a distance, and few details can actually be seen. Valuable inferences may be drawn by remembering that the enemy has probably chosen his position in accordance with the principles above given.

Especial attention should be given to the flanks and the feasibility of turning one of them.

65. A **position sketch** will usually be on a scale of 6 inches or 12 inches to the mile. It will be found most convenient and expeditious to make it by the compass and drawing-board method (par. 50) or the method with oriented board alone (par. 54). The traverse will include the fewest points from which the entire area can be seen, often only two, and all other features will be located by intersections from these points. Elevations may be taken by slope board or clinometer, the height of the first point occupied being rbitrarily assumed if not known.

f two points can be found which overlook the area is front of n and which are also visible from each other, **the compass may dispensed with** except for a meridian. Measure the distance n the two points. Assume the position of one of the points the line joining them, so as to bring the desired area on the rom the first point lay off on the line the distance between oints to the adopted scale and plot the second point. The line joining the two is called the **base,** and will be near one edge of the board if all the area to be mapped is on one side of the line or toward the middle if it is on both sides.

Place the board over the first point; lay the ruler along the base and turn the board until the ruler points to the second point. Keep the board in this position and point the ruler successively to the objects to be located, drawing the lines as explained in paragraph 54. Gradients are written along the corresponding azimuths. One gradient should be taken to each point determined.

Proceed to the second point. Lay the ruler along the base and point it to the first point. Point the ruler to the objects to be located, marking where it crosses the line to the same object drawn from the first point.

66. **Contouring** is a method of exhibiting relief of ground by means of lines so drawn on a map as to indicate points of equal elevation. The lines so drawn on a map and the corresponding lines on the ground are called *contours.* The word *contouring* is applied to the fieldwork directed especially to obtaining data for drawing contours.

The difference of elevation of points in adjacent contours is called the **contour interval,** and is usually constant for all the contours on the same map. The horizontal distance between contours, measured in a radial direction with reference to the curvature of the contours will be referred to as **contour distance.**

The theory of contouring is that no inadmissible error will be made by supposing the slope of the ground from a point in one contour to the corresponding point in the next, or along the contour distance, to be a straight line. The less the contour interval, the less error will be made. If in figure 28 the curved line *AB* represents the actual surface of the ground, and points 1, 3, 5, the elevation of successive contours, the broken line 1, 3, 5, will represent the assumed ground surface, and its departure from the line *AB* is the error introduced. If now the points 2, 4, and 6 are also determined, or the contour intervals be reduced one-half, the assumed slope is 1, 2, 3, 4, 5, 6, which differs less from the line *AB* than the line 1, 3, 5, and hence introduces less error. With points determined at very short intervals the error is practically eliminated.

If contour distances **decrease** with **elevation,** or the contours become closer as they go higher, the **slope is concave,** and points between contours are lower than the straight line joining corresponding contour points. If the contours become closer as the ground falls, the ground is **convex,** or lies above the straight line joining corresponding contour points. A **point of inflection,** or change from convex to concave, is at the point where the contour distance is less or greater than those on either side of it. **Equal** contour distances correspond to uniform slope.

67. One contour does not necessarily join all the points of the same elevation on the map but only those which have a continuous series of points of the same elevation joining them. It may require several contours to take in all the points of a given elevation on the map. Parts of the same contour will appear as separate when the ground over which they could be connected is not on the map. The selection of the points to connect in one contour is the difficult part of the process and can not be done correctly without thorough knowledge of the principles of the method and a good idea of the general shape of the ground to be contoured. In military reconnaissance only enough elevations can usually be taken in the field to guide one who has seen and studied the ground in drawing the contours. No one who has not seen and studied the ground should be expected or permitted to draw contours from such data. Erroneous information may be worse than none at all.

68. For equal contour intervals the map contours are closer together as the slope is steeper. It follows that for steep slopes the *map contours* will approach each other very closely, and for a *vertical wall or cliff* they will coincide.

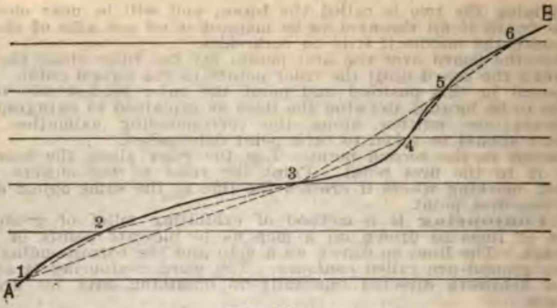


Fig. 28

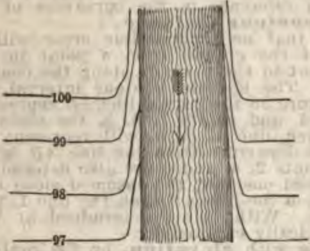


Fig. 29

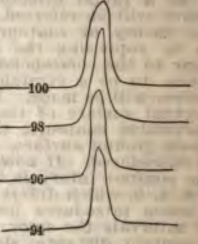


Fig. 30

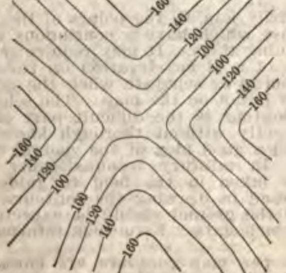
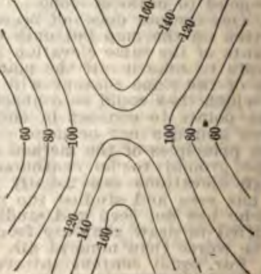


Fig. 31



Fig˙ 32

Ground contours can not cross, but map contours may cross in the very unusual case of a cave or a bluff overhanging by an amount which can be shown on the horizontal scale. This is so rare that it is usual to say that map contours can not cross.

Every contour must close upon itself in a loop or else must extend unbroken from one point on the margin on the map to some other point on the margin. An exception is made in the case of large streams, the contour on each bank being carried upstream until it cuts the water surface when it is dropped. The two ends must be directly opposite (fig. 29). In a small stream or dry bed, the contour crosses at the point where the elevation of the bed is that of the contour (fig. 30).

Maximum ridge and **minimum** valley contours go in pairs. A single lower contour can not lie between two higher ones, or a single higher between two lower. When two **adjacent contours** have the **same elevation,** the ground between them will be **still lower** if they are valley, or **still higher** if ridge contours.

69. Contours are designated by their heights above a datum plane. The height is expressed in feet, except when the metric scale is used, when contour intervals are in meters.

The elevation of each contour should be shown in figures at points close enough together to allow the eye to run from one to the other with ease. It is best to break the contours and write the numbers between the ends. If written alongside, the numbers should always be on the higher side of the contour (figs. 31 and 32).

70. Straight contours are very rare. They may be determined by locating any two points, or by locating one point and observing the azimuth of the line.

Simple curved contours are more frequent than straight ones, but are not often found of any considerable length. They may be determined by fixing 3 points; or by 2 points with the radius estimated; or by 1 point with the center assumed.

The **typical contour** is a **wavy** line, alternately salient and reentrant, and may be determined with the precision needful for hasty reconnaissance by fixing the extreme points of the convex and concave portions.

71. Looking at contours from the higher side, the salient parts, or those concave to the observer, correspond to the ridges, and the reentrant parts, or those convex to the observer, to the valleys. The valleys are also lines of drainage. Hence, half of the points necessary to determine a wavy contour will lie on drainage lines, as indicated by rivers, creeks, brooks, and rivulets, and by ravines, or other depressions dry at most seasons.

The slope of a drainage line grows less in the direction of flow. Tributaries, or branches, are usually steeper than the main stream at their junction, and also increase in slope toward their sources. Generally, in a limited area, the sources will be at nearly the same elevation. To apply this principle in increasing the amount of topographical relief that may legitimately be drawn from a given number of known elevations, let figure 33 represent the drainage lines of an area taken from a civil map. Suppose the ground to have been studied and elevations to have been determined at 2 points, *A* and *B*. How much topography can be drawn?

The 110-foot contour will be above the 105-foot and by a distance somewhat less than the length *AB*, because the slope becomes steeper and the contour distance less in going upstream. The succeeding contours at 10-foot intervals will cross the tributary at gradually decreasing distances, as indicated, and for the same reason. The source is found to be about 130 feet. Take the other sources to be also 130 feet and draw the contour at that level, remembering that it is concave where it crosses the streams, and that the part between the streams is convex and advanced. Lay off the contour points on the other stream lines, keeping in mind the law of slopes, and draw the other contours, following the same rule as for the first.

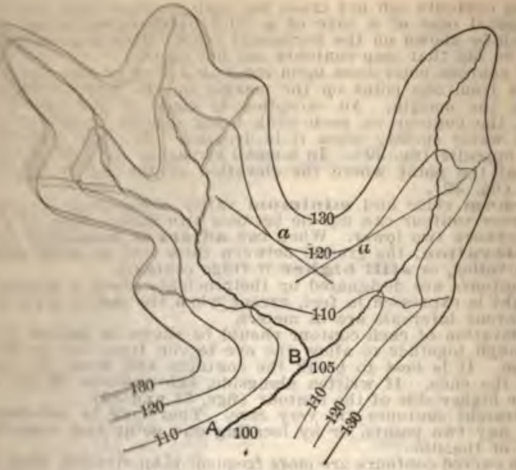

a
a
B
A

Fig. 33

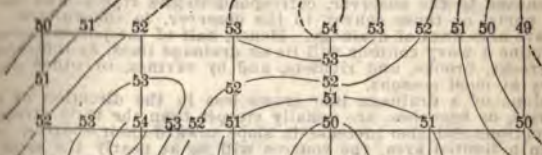


Fig. 34

72. If enough elevations were taken on stream lines the concave parts of the contours would be fairly well determined, but the convex points would still be in part uncertain. It is known that they are convex and salient, but not how much. This information is supplied by elevations taken along the ridges, crests, or divides which lie between adjacent drainage lines. The typical profile of a crest is a reversed curve, flat and convex between the sources of streams, flat and concave near the junctions of streams, and steepest in the middle, with the inflection at the steepest point. The form of crests is not so regular as that of valleys, and less use can be made of it. It should be kept in mind as a basis of comparison, so that actual forms can be more readily remembered.

73. **The field work of contouring** an area which has a sufficient relief to exhibit drainage lines clearly may begin by traversing these lines with gradients taken by clinometer or slope board. It is most convenient to begin where collected drainage leaves the area to be mapped and follow each valley to its source.

If the valley is open and the flanks of the ridges on each side can be seen, time may be saved by taking level sights from some of the contour points on the drainage line to points on the ridges as far advanced as possible, usually where the line of sight is tangent to the hill. This gives two points, *a a* (fig. 33) near the apex of the salient from which the contour may be drawn often as well as by a point at the apex. If this can be generally done it may not be necessary to run out the ridges. Notes should be made of the apparent shape of the contours near the drainage line, whether sharp or blunt, or whether the valley is narrow or wide. The general shape of the sky line of the ridge or its projection against higher ground should be noted whenever a lateral view of it can be had.

If hill points can not be taken from the valley traverse the ridge lines must be run out. They must be connected in plan (distance and azimuth) and in elevation with the drainage lines. When drainage and ridge lines are plotted on the map the contour points, if not actually observed, may be interpolated and the contours drawn.

The symmetry of adjacent contours is obvious from the inspection of any contoured map, and this relation may be utilized where one contour has been well determined, to draw the one on either side of it from a very few points, often but one. If the contours are wavy they will generally be a little farther apart at the concave and convex points than at the reversion points between them. If the contours are not wavy they are generally parallel.

74. If the **relief** of the ground is so **slight** that the drainage and ridge lines are uncertain the field work of contouring is best done by taking elevations at points arbitrarily selected. Such points will usually be in straight lines running in the general direction of the steepest slope. The points are plotted on the map, the corresponding elevations written near them, and the contours are interpolated as indicated in figure 34, assuming that the surface of the ground between observed points is a straight line. The closer the points are together the less error is involved in this assumption.

If the country is comparatively flat and unbroken, profiles may be run along roads and paths and contours sketched in on each side so far as they can be seen. Then by going over the intervening ground and observing its shape, the portions drawn can be joined with the eye with sufficient accuracy.

In towns and villages profiles along intersecting streets and the study of the intervening space furnish data for approximate contours.

75. **Slope equivalents.**—Actual distances between contours on a map depend on the contour interval, the scale of the map, and the gradient. For any given map the contour interval and scale are constant, and the distances between contours depend on the slope alone. *On any map with contours at equal intervals each gradient has its corresponding contour distance, which is called its* **equiva-**

lent. A line subdivided to show the equivalents of various gradients on any map is called a **scale of slope equivalents** for that map, or simply the **scale of slopes,** and by applying such a scale to the distance between two successive contours the slope of the ground between them may be read off.

For different maps slope equivalents vary with the ratio between the contour interval and the scale. A scale of slope equivalents may be constructed for a given ratio and will be true for all maps having that ratio, no matter how much the scales may vary. The ratio may be taken as the fraction of an inch on the scale of the map corresponding to the contour interval. If the scale of the map is 500 feet to the inch and the contour interval 1 foot the ratio is $\frac{1}{500}$ or 0.002, which is the fraction of an inch corresponding to 1 foot on a scale of 500 feet to the inch. If the scale is 1,000, 5,000, 10,000, or 50,000 feet to the inch and the corresponding contour interval is 2, 10, 20, or 100 feet the ratio in each case is $\frac{1}{500}$, and the contour interval corresponds to 0.002 inch on the scale of the map, and a scale of slope equivalents corresponding to the ratio applies.

Figure 35 contains scales of slope equivalents for ratios of $\frac{1}{500}$ to $\frac{1}{5000}$, which will cover the usual range.

To get any desired scale of slope equivalents from the figure, divide the number of feet in the contour interval by the number of feet per inch of the scale, or divide the number of *inches* in the contour interval by the denominator of the R. F. The result is the **ratio.** Place the straight edge of a piece of paper horizontally on the diagram and passing through the corresponding point on the ratio scale on the left of the figure and prick off the scale.

Slope equivalents afford a convenient and rapid method of determining contour points on any line of a map the gradient of which is known.

Any fraction of the equivalent for any slope corresponds to the same fraction of the contour interval. If an end of the line is on a contour the slope equivalent may be stepped off along the line and each point so determined will be a contour point. If the end of the line is between contours, measure off on the line the part of the slope equivalent corresponding to the rise or fall to the next contour point. From this step off the slope equivalent as before. If a fractional distance remains at the end of the line find what part of the slope equivalent it is and add to or subtract from the last contour elevation the corresponding part of the contour interval for the elevation of the end of the line. To illustrate: If in figure 36 elevation at a of the line ab is 103, gradient +2°, the contour interval 10 feet and the slope equivalent cd, then the rise to the next contour is $110-103=7$ feet, or $\frac{7}{10}$ of the contour interval. Seven-tenths of $cd=ae$, and hence e is the position of the 110-foot contour point. Lay off ef, fg, and $gh=cd$ and locate the 120 feet, 130-foot, and 140-foot contour points. The remaining distance $hb=\frac{1}{4}$ of cd, hence the rise beyond $h=2\frac{1}{2}$ feet and the elevation of $b=$ contour point. Lay off ef, fg, and $gh=cd$ and locate the 120-foot, 142.5.

76. In the absence of contours relief may be indicated by **hachures,** which are short parellel or slightly divergent lines running in the direction of the steepest slope. Hachures should be used only to indicate areas which present slopes steep enough to offer cover or become obstacles. The use of hachures is illustrated in figure 37.

77. The **reconnaissance with a moving column** will require the simultaneous work of a number of sketchers and must be so organized that each sketcher shall do his full share in the time allowed; that the sketches and reports shall be turned in about the hour; and that the assigned ground shall be thoroughly cov-
without unnecessary duplication.

good sketcher on foot can take about 10 miles of road in a day, n keep up with a slowly advancing column. A good sketcher

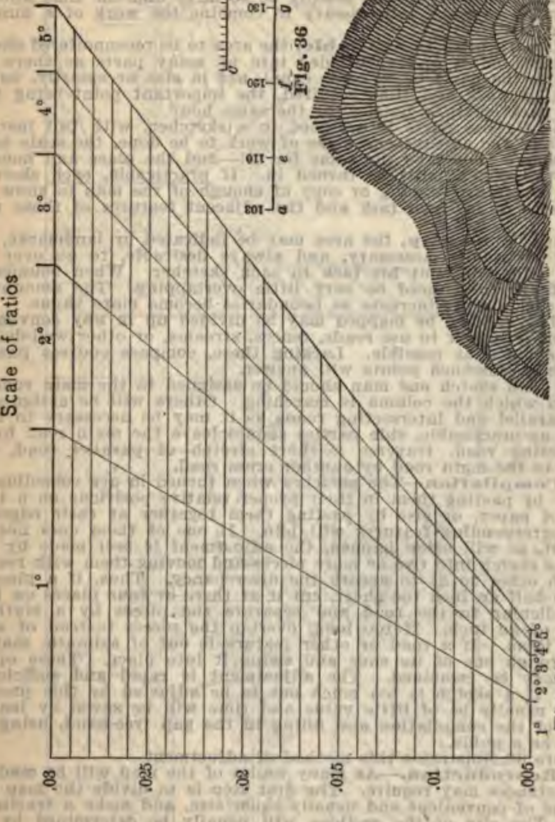


Fig. 35

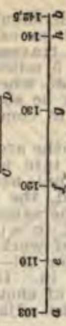


Fig. 36

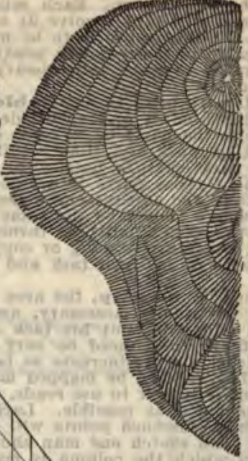


Fig. 37

mounted can cover 15 miles a day steadily, or in an emergency 20 or 25, and can keep up with infantry on a forced march or with cavalry marching at ordinary rate.

The reconnaissance for a column should include besides the road traveled the nearest parallel road on each side and all connecting roads between them. Each mile traversed by the column on the main road will thus involve 2½ to 5 miles of sketching.

If a reconnaissance is to be made when a force is not in motion, the area to be covered will usually be so large and the time allowed so short as to make it necessary to combine the work of a number of sketchers.

78. **If any map is available,** the area to be reconnoitered should be outlined on it and subdivided into as many parts as there are sketchers, the parts to be made equal, not in size necessarily, but in amount of work and time required, the important point being that all the parts shall be finished at the same hour.

Each of these parts is assigned to a sketcher, with full instructions as to the amount and class of work to be done, the scale to be used—which should be the same for all—and the place and hour at which the sketch must be turned in. If practicable, each sketcher should be given a tracing or copy of enough of the map to show the boundaries of his own task and the adjacent features of those next to his.

If there is **no map,** the area may be indicated by landmarks, but it will be usually necessary, and always desirable, to go over the ground and point out his task to each sketcher. When boundaries are definite there need be very little overlapping. The amount of reduplication must increase as boundaries become more vague.

79. The area to be mapped may be divided up in any convenient way, but it is best to use roads, fences, streams, or other well-defined lines as much as possible. Lacking these, compass courses passing through well-defined points will answer.

In a road sketch one man should be assigned to the main road or that on which the column is marching. Others will be assigned to such parallel and intersecting roads as it may be necessary to map. So far as practicable, side parties should leave the main road by an intersecting road, traverse a short stretch of parallel road, and return to the main road by another cross road.

80. **Compilation**—The sketches when turned in are consolidated, usually by pasting them in their proper relative positions on a large sheet of paper, or else by pasting them together at their edges so that corresponding features will join. If one of them does not exactly fit, as will often happen, the adjustment is best made by cutting the sketch into two or more pieces and moving them with respect to each other so as to absorb the discrepancy. Thus, if a piece of road is half an inch too short, cut it at three or four places on lines perpendicular to the road and separate the pieces by a sixth or eighth of an inch. If too long, overlap the pieces instead of separating them. If a road or other feature is out of azimuth, make a cut through one of its ends and swing it into place. These operations may be combined. The adjustment is rapid and sufficiently exact. If a sketch is too much out to be adjusted by this process, it will usually be of little value and time will be saved by leaving it out of the compilation and filling in the gap free-hand, using the sketch as a guide.

Figure 38 illustrates this method of adjustment.

81. **Reproduction.**—As many copies of the map will be made as circumstances may require. The first step is to divide the map into sections of convenient and usually equal size, and make a tracing of h. The size of the sections will usually be determined by the hod of reproduction to be used and the size of the apparatus at d. Time will be saved if there are not more sections than there nen available to trace, supposing that all the tracers are of ap- mately the same speed. If one of them can work two or three

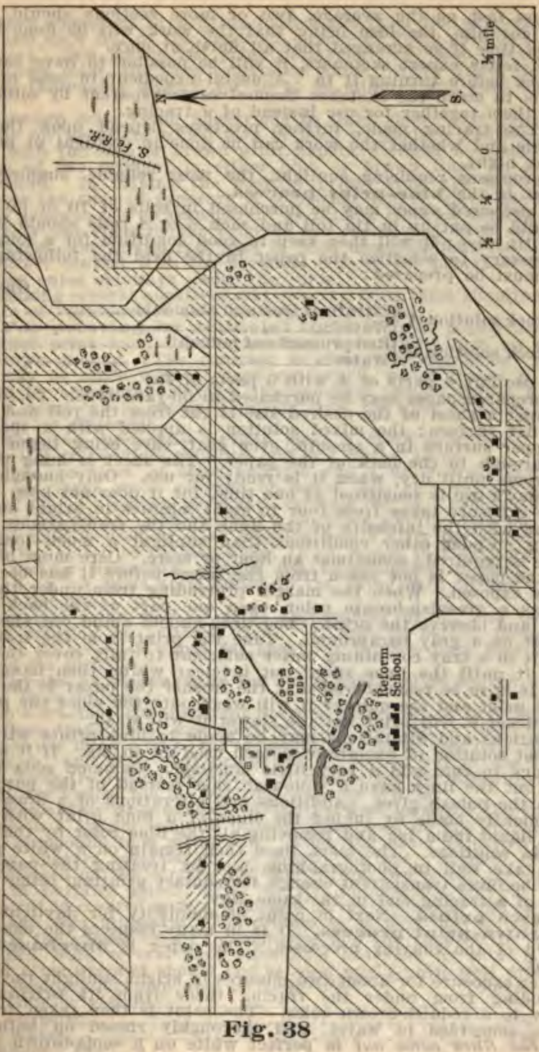


Fig. 38

times as fast as the average, two or more sections should be reserved for him, the idea being that the work will be done in the shortest time if so arranged that all finish at once.

With fairly expert sketchers, it will be possible to have each ink his work before turning it in. A useful expedient in case of great haste is to make the sketches themselves transparent by oiling and fasten them together for use instead of a tracing.

82. The tracing made, further processes depend upon the time available and whether the work can be done in daylight or must be done at night.

Of processes requiring sunlight, the most reliable, simplest, and quickest is the **blue-print process.**

The *prepared paper* may be purchased in rolls of 10 or 50 yards. It should be put up in tin foil and each 6 or 8 rolls should be in a sealed tin case; it will then keep in good condition for a long time. If necessary to sensitize the paper in the field the following solutions must be prepared:

		Ounces.
Stock solution **A**	Citrate of iron and ammonia	2
	Water	8
Stock solution **B**	Red prussiate of potash	2
	Water	8

For use mix 4 parts of **A** with 3 parts of **B.**

Unprepared paper may be purchased in 50-yard rolls. To sensitize the paper a sheet of the desired size is cut from the roll and placed on a flat surface; the mixed solution is applied with a sponge to the upper surface in a smooth, even coat, care being taken not to wet through to the back of the paper. The sheet is hung up in a dark room until dry, when it is ready for use. Only enough paper for a day's use is sensitized at one time, for it does not keep well.

The exposure takes from four to eight minutes in bright sunlight, varying with the intensity of the light and the transparency of the tracing. Under other conditions than sunlight a much longer exposure is required; sometimes an hour or more. Care must be taken that the paper is not taken from the frame before it has been sufficiently exposed. When the margin protruding from under the tracing has a greenish-bronze color, open one part of the back of the frame and observe the print. The lines should stand out sharp and distinct on a gray background. Take the print from the frame and place it in a tray containing water sufficient to fully cover the print. Rinse it until the lines stand out in clear white, then hang up to dry. It is to be remembered that the fresher the paper is the slower it will print and the quicker it will wash out; the older the paper is the quicker it will print but the slower it will wash.

Additions and alterations may be made to blue prints with a 10 per cent solution of oxalate of potash used as an ink. If it shows a tendency to run, add a very little mucilage. Common soda may be used, but the lines have a yellowish cast instead of the pure white which the potash gives. Additions and alterations of a drawing are conveniently made by inking the lines of a blue print with waterproof liquid india ink and removing all the blue color by the potash or soda solutions. The black lines then remain on a white ground. They take well in photographing, and by treating the paper with oil, it becomes transparent enough for contact printing, being used in place of a tracing and in the same way.

Brown prints.—Next in point of simplicity for daylight use is the **brown-print process.** It is in many respects the most satisfactory of the copying processes. The paper is **purchased pre-**
d.

r exposure for about two minutes in bright sunlight the margin ding from under the tracing turns from its original light to a reddish-brown color. The print is then taken from the immersed in water, and thoroughly rinsed on both sides, he lines come out in perfect white on a sepia-brown ground.

It is then immersed in a fixing bath made from the salt which accompanies each roll of the paper (2 ounces of fixing salt to 1 gallon of water); this makes the print permanent and also darkens the sepia-brown color, the lines remaining white. After fixing the print must be thoroughly washed for 20 to 30 minutes and then hung up to dry.

The brown color being impervious to light makes this paper very valuable for negatives which may be used to produce positive copies, either with the blue or brown print papers, yielding an exact reproduction of the original in either blue or brown lines on a white background. In making the positive prints from the brown-paper negatives the time of exposure is somewhat longer, since the brown-process paper is not as transparent as tracing cloth or tracing paper. Even very fine lines of the original are reproduced with surprising distinctness, due to the fact that in both manipulations the orgiinal is in direct contact with the sensitive side of the paper, so that no light can enter sideways under the lines.

By making several negatives and printing from them simultaneously the rate of reproduction may be largely increased.

83. **For printing by artificial light** bromide papers are used. A contact print from the tracing has clear white lines on a very dark-brown ground. The contrast is clear and agreeable. Alterations may be made with a sharp red pencil, which makes a legible line, or by scratching through the emulsion, which makes a white line. A print can be obtained quickly from the light of three candles at 12 inches distance.

To **develop bromide prints** make a stock solution of hydrochinon, 150 gr.; sodium sulphite, 360 gr.; water, 12 oz.

For use, to 1 oz. of stock solution add 1 dr. rodinal and 8 oz. water; or, make stock solution of metol, 150 gr.; sodium sulphite crystals, 2½ oz.; sodium carbonate crystals, 3½ oz.; bromide potash, 8 gr.; water, 20 oz. For use, add 1 oz. stock solution to 4 oz. water.

Acetic acid is used to clear bromide prints after development and to stop the action of the developer, 16 oz. water to 1 dr. acetic acid.

For **fixing bromide prints** use hyposulphite of soda, 1 oz.; water, 6 oz. A little alum added to the fixing bath in hot weather hardens the film.

A bromide print may be made transparent by oil and used for contact printing by artificial light. It will be better, though not essential, to secure a paper for negatives thinner than that usually supplied for prints.

The **cycle of operations** for quick reproduction by the bromide process is as follows:

From a tracing or transparent drawing make, say, 3 to 5 negatives. Make them transparent and start printing from all of them. If the sketchers are in by 5.30 p. m., the negatives can be ready for printing by 7 p. m., and after that prints can be turned out at the rate of 15 per hour from each negative. It should not be difficult to have all that are needed for the next day done by 9 p. m.

84. **Transfer processes.**—With the **hectograph** the drawing is made in a special ink and pressed face down on the surface of a gelatin compound in a metal pan. When the paper is pulled off the drawing appears reversed on the gelatin surface. A piece of blank paper pressed on the surface and then withdrawn shows the drawing direct in purplish lines. Fifty to 100 impressions may be taken. Each print is covered with a thin film of the compound and is sticky, curly, and very stubborn. The process is at best only a makeshift, but it is the easiest of all to improvise and the simplest to operate. For quick work several pans should be provided, as each must be washed after use and should not be used again until well dried.

The hectograph compound is made of—

	Parts.
Glue or gelatin	100
Glycerin	400
Water	400

Kaolin, 50 parts, or some fine inert light-colored powder may be added with advantage. The ingredients require prolonged mixing at 200° F., which is best obtaised in a salt-water bath, 2 ounces salt to 1 pint water.

The ink is made of—

	Parts.
Nigrosine black	1
Glycerin	4
Water	14

Writing or drawing is done with a fresh, clean steel pen. The surface of the compound is moistened lightly with a brush or sponge and allowed to **nearly dry,** when the copy is laid smoothly on face down and rubbed to a good contact throughout, eliminating all air bubbles. The paper is allowed remain two or three minutes and then removed by starting one corner and pulling parallel to the surface. The sheets for impressions are put on and removed in the same way, except that they are left on but few seconds.

With the **black autocopyist** the drawing is made in a special ink and transferred to a parchment sheet held in a special frame. This process is free from some of the objections to the hectograph, but it is more difficult to work. The copies are in printer's ink, are permanent, and very satisfactory.

85. **Landscape sketching.**—Free-hand sketching can not take the place of topography, but it is a valuable adjunct and should be practiced by every soldier who has any aptitude for pictorial drawing.

A sketch differs from a photograph only in that it shows in sharp outline a limited number of the larger and characteristic features easily seen and understood, while the photograph shows all details, many of them so minute that they are lost in a mass of confused forms, with the form lines, other than the sky line, relatively inconspicuous. All the lines of a perfect sketch exist in a photograph, but close scrutiny is often necessary to find them. If sought out and traced, however, a perfect sketch results. Tracing from photographs is excellent practice.

The outfit for field sketching should be as simple as possible. A sketchbook with a canvas cover, carried in a water-tight case, together with a few lead pencils B, F, and H, and pieces of soft and hard rubber are the essentials for satisfactory work. For active field work the book should be no wider than can be carried in the pocket of a service blouse and relatively long, say 5 by 9 inches.

The **point of view** should as a rule be high enough to give a comprehensive grasp of all that is important—a rock, a knoll, a hill, a peak—depending upon the conditions. Face toward the middle of the field of view which is determined upon. Hold the board or sketchbook vertically before the eye and move it backward or forward until the sheet just fills the field. Lower the board until the sky line of the hills can be seen above its top edge, and with a pencil mark on that edge the points corresponding to the principal salients and reentrants of the hill forms. If desirable the board can be moved sideways far enough to enable the principal heights and depressions to be marked on the vertical edge. By intersecting references the locations can then be easily established on the sheet. From these points the forms can be sketched in with much greater accuracy.

Proceed next to draw the hills in outline, but faintly, with attention to the larger curves or humps at first. Go over them again with more care, bringing out the small irregularities. If any part of the horizon is visible, draw in lightly, and then complete the general mass of hills by drawing the water or base lines. Seek now for the surface character of the hills by tracing the ravine lines. The knobs and foothills are brought out by tracing the tree meanders that show form. All changes in form or breaks in the ground produce orresponding breaks in the foilage of the tree masses, which show n the distance as irregular lines. If the more important of these e sought and drawn, the general character of the hill will result.

Add now the foreground crest, and the skeleton of the sketch is complete.

The road and railroad meanders should follow as a rule, and the fences of the fields. Cultivated land is rendered by parallel irregularly broken lines. Houses, fortifications, trenches, etc., will be drawn more or less in detail according to distance and importance. Enemy's lines or trenches even at a greater distance should be strongly marked by simple black lines. The indication of forests and trees is the most difficult feature for students. The indications given in the accompanying sketches will show the treatment in outline work.

Figures 39 and 40 show a variety of forms sufficient for most localities.

86. **Hydrography.**—Depth of water and character of bottom are determined by sounding with a pole or with a lead and line. **The sounding pole** may be improvised, or of permanent form. A convenient one is 10 feet long, octagonal in section, tapering slightly from middle to ends, divided into feet which are painted alternately white, and black or red. There should be an iron shoe at the bottom, heavy enough to make the rod stand erect when free in deep water. Such a rod is convenient to use in water 9 feet or less in depth.

If a sounding lead is not furnished, any compact weight may be used. The **sounding line** should be of braided hemp or cotton, $\frac{3}{8}$ to $\frac{1}{2}$ inch in diameter, and tagged with cloth or leather. The tagging will depend on the depth to be measured and degree of precision required. Cloth of different colors may be used for different units, and leather tags may be distinguished by cutting notches or punching holes in them. The line should be thoroughly wet, stretched, and allowed to dry. It should then be wet again and tagged while wet. The zero of the graduation is at the bottom of the lead or weight. A lead and line are best connected by a rawhide thong passing through an eye in the lead and an eye made in the end of the line.

Soundings are usually referred to a plane parallel to the water surface, horizontal except in flowing streams. The plane usually selected is the water surface itself if stationary, or one of its positions if variable, so that soundings will indicate approximately the actual depths of water. The elevation of the water surface in the position selected is called the **datum level.** If the surface elevation varies, a gauge rod must be set near the water's edge, and read often enough to plot a continuous curve of water level. The time of beginning and ending a particular group of soundings is noted. The mean elevation of the water surface during that interval is taken from the curve, and the soundings are corrected by the difference between the actual level and the datum level. If the correction to be applied is less than half a foot, it is usually neglected.

The material of the bottom, as rock, gravel, sand, or mud, can usually be told from the feeling of the rod or lead when it strikes. A specimen of the bottom can be brought up by smearing the end of the lead with tallow.

A correct sounding is obtained only when the line or rod is plumb and straight and its length correct, or its error known and applied. Except for blunders in reading the line, only one source of error operates to make the soundings too small, and that is a line which has stretched since it was tagged or is too long. All other sources of error make the soundings too large, and hence they are apt to be so, and actual depths slightly less than those recorded will usually be found.

To get a plumb sounding from a boat moving through the water, the lead is thrown out or the pole inclined in the direction of motion far enough to allow it to reach bottom by the time the boat is directly over the spot where it strikes. Soundings taken with a line from a moving boat will always be too large.

The most accurate soundings with lead and line in running water are taken from a boat floating with the current, with line allowed to

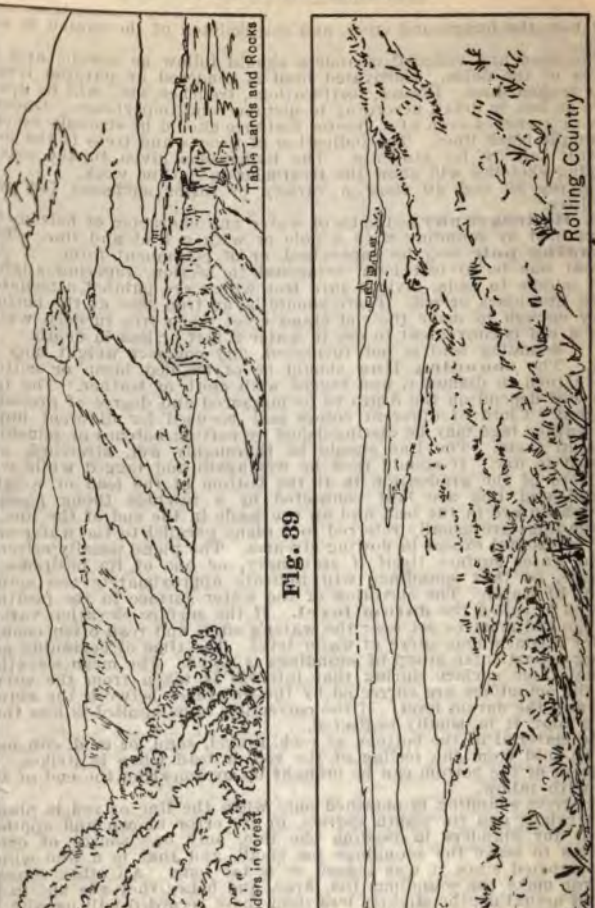


Table Lands and Rocks
Tree meanders in forest
Rolling Country

Fig. 39

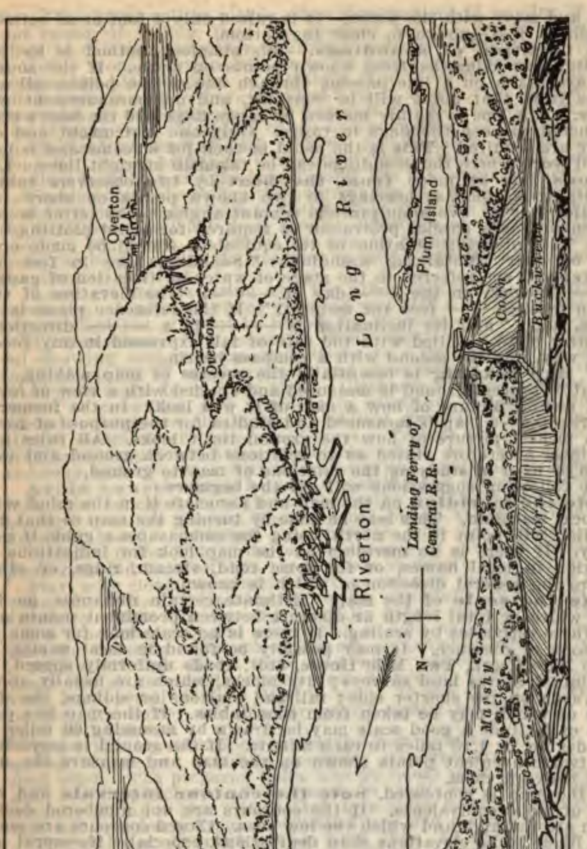

Overton
Overton
Road
Long River
Plum Island
Riverton
Landing Ferry of Central R.R.
N
Corn
Corn
Buckwheat
Buckwheat
Marshy
Marsh
East Bank R.R.
West Bank R.R.

Fig. 40

hang and move with the water. It is raised only a foot or so between soundings, just enough to clear the bottom.

87. **Location of soundings.**—The simplest method is by two simultaneous azimuths from known points on shore. If the soundings are taken on a line passing through one of the points, all azimuths from that point will be constant, and one measurement will suffice. This line is plainly marked by range flags and the boat's crew instructed to keep the flags in range. Only one instrument and observer are required. This is the usual method for streams and is best for all work where the soundings can be taken in straight lines. **Locations** may be made **from the boat** by two observers taking simultaneous compass bearings to two known points on shore—see resection—or by two simultaneous sextant angles. The latter is less convenient, as a special protractor is required for rapid plotting.

88. The following notation or its equivalent should be made on a map or chart containing soundings: "Soundings are in feet (or meters) and are referred to the stage of water at (location of gauge) at —— o'clock, on the —— day of ———. The elevation of this datum level is —— feet (or meters)." If the reference plane is inclined, add: "and its inclination is ——— in a ——— direction." The first blank is filled with the rate of fall expressed in any recognized way, and the second with a compass bearing.

89. **Map reading** is essentially the reverse of map making. In the latter process ground is measured and studied with a view of forming a mental picture of how a map of it will look. In the former—map reading—a map is measured and studied for the purpose of forming a mental picture of how the ground itself looks. All rules and principles heretofore stated as to relations between ground and map are to be used in studying the relations of map to ground.

The following suggestions will aid the beginner:

Note the meridian on the map and associate it in the mind with the local meridian. This may be done by turning the map so that the meridian will point to the north, using the compass as a guide if necessary. If there is no meridian on the map look for indications of direction in local names, or for some road, stream, ridge, or other feature the general direction of which is known.

Note the scale of the map. Estimate certain distances, as the total width or total length or distance between prominent points and test these estimates by scaling. If there is no scale look for some indications of distance. It may possibly be found in local names, as Three Mile Creek, Two Mile House, etc.; roads uniformly spaced, as the United States land surveys; city blocks, which are usually about 100 yards on the shorter side; railroad stations or sidings, the distance of which may be taken from time tables. If the map has parallels of latitude a good scale may be drawn by assuming 69 miles to each degree, or 1.15 miles to each minute. If the ground is accessible take two convenient points shown on the map and measure the distance between them.

If the map is contoured, **note the contour intervals** and the scale of slope equivalents. If the contours are not numbered decide which are the high and which the low ones. Closed contours are much more likely to be elevations than depressions, especially if several are concentric. A single closed contour may be uncertain. Look for indications of marsh or water inside of it. If the contour interval is not given it will be difficult to get any clue to it unless isolated elevations appear on the map. If the ground is accessible the contour interval may be determined by actual measurement of a gradient.

Note all topographical and cultural signs and associate them in mind with their advantages or disadvantages for military operations.

90. A problem frequently arising in map reading is that of determining **what points are visible from a given point.** A point is visible when the gradient to it, if rising, is greater, and, if falling, is smaller than the gradient to any intermediate point.

For this comparison gradients are conveniently represented by the *quotient of distance* in feet divided by the difference of elevation in feet. The point will be visible when this quotient is smaller, if rising, and larger, if falling, than the quotient for the intermediate point. Thus, to determine whether the bridge near the Frenchman's (fig. 41) is visible from Atchison Hill or is concealed by intermediate ground, assume the highest point of Atchison Hill to be in the center of the 1,040 contour and to have an elevation of 1,050. The distance from this point to the bridge is 5,610 feet, fall 250 feet, quotient 22.4. The line of sight from this point to the bridge crosses the 960-foot contour on the flank of Sentinel Hill at 3,060 feet distance, fall 90 feet, quotient 34; hence bridge is not visible from Atchison Hill, since the gradient is falling and the nearer point has the larger quotient.

Working from the bridge the quotient for the whole distance is 22.4, as before, but the gradient is rising. The distance from the bridge to the high point is 2,550 feet, rising; difference of elevation 160 feet, quotient 16; hence, as before, the top of Atchison Hill is not visible from the bridge, since the gradient is rising and the nearer point has the smaller quotient.

If one gradient is rising and the other falling, no computation is necessary. A point of rising gradient will hide a farther point of falling gradient but will not be hidden by a nearer one.

91. **Drawing.**—The essential requirements of a good topographical drawing are *accuracy* and *clearness*. By accuracy is meant a faithful exhibit of measurements and observations made in the field, or of data taken from other maps. Clearness involves absence of confusion or crowding, and neatness in execution. **Beauty and pictorial effect** are obtainable by skilled draftsmen only, and while always desirable are rarely necessary. Persons who are not skilled draftsmen should not attempt pictorial effect, as it will detract from accuracy and clearness without substituting anything of equal value.

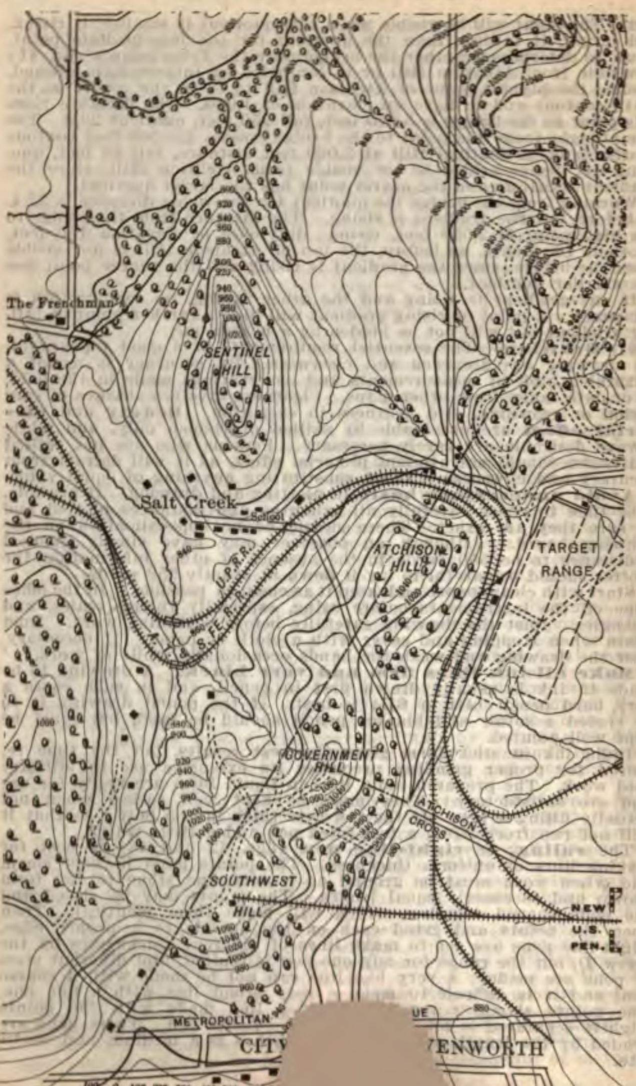
Avoid unnecessary haste in plotting and drawing. If possible, take time to check carefully all azimuths and distances plotted and be sure they are exact. There should be no approximation on the drawing board. Although an observer may have simply guessed a distance to be 550 yards in the absence of other information the plotter should be careful to lay it down at exactly 550 yards.

Start with clean paper and keep it as clean as possible. In the office wipe off the instruments before using, especially rulers, scales, and triangles. Dust the drawing carefully before beginning work. Dust again when stopping and cover with a cloth or paper. If necessary, dust the drawing and wash the hands occasionally while at work.

Make all ink lines firm and very black. A drawing to be made in ink is usually drawn first in pencil, and in such cases a very hard pencil (4H or 6H) is best. If the pencil drawing is to be traced a softer and blacker pencil should be used, but must be kept well pointed.

India ink in stick form gives the best results, but the time required for proper grinding precludes its extensive use in military field work. The prepared India inks in liquid form are ready for use and are satisfactory. They must be kept well corked when not actually filling a pen. If the ink gets thick in the bottle so that it will not run freely from a fesh-filled pen add a little water.

The **ruling, or right-line pen** (figs. 42 and 43) is best for making lines of uniform thickness. The points must be kept clean, and when worn must be ground on a very fine stone to the form shown and to exactly equal length. The points may be closed and the ends shaped together, which will make them identical. Then open the points and grind each on the outside to a proper edge. Right-line pens are set to make lines of different thicknesses by the screw *D*, but the range for any one pen is limited, and different sizes of pens are made. A very fine line can not be made with a coarse pen, and it is difficult to make a very broad line with a fine one. The points should never touch. If a line made with the points slightly separated is too coarse, take a smaller pen. These pens are graded by the length over all. Five inches is a medium and useful size.


The Frenchman's
SENTINEL HILL
Salt Creek
School
U.P.R.R.
A.T. & S.FE.R.R.
ATCHISON HILL
TARGET RANGE
SHERIDAN DRIVE
GOVERNMENT HILL
ATCHISON CROSS.
SOUTHWEST HILL
NEW U.S. PEN.
METROPOLITAN
UE
CITY
VENWORTH
100 0 100 200 300 400 500 600

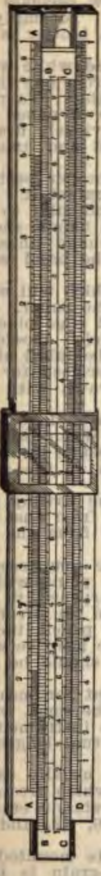


Fig. 47

Fig. 45

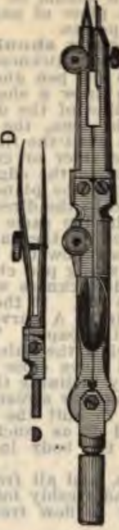


Fig. 43

Fig. 42

Fig. 44

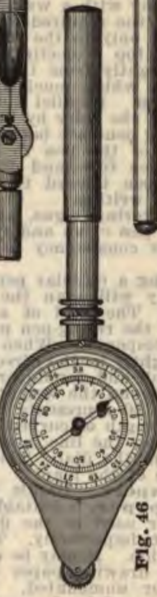


Fig. 46

Right-line pens may be filled by dipping an ordinary pen in the ink and inserting it between the points. A strip of paper closely folded may be used in the same way. In the bottle of prepared ink the cork carries a small quill for filling. Take only as much ink as can be used in two or three minutes. As soon as the flow becomes the least sluggish, the pen should be emptied and refilled. To empty or clean the pen pass a piece of paper (the corner of a blotter is excellent) between the points.

The adjusting screw should not be disturbed while working on lines of the same thickness. When changing from one thickness to another, open the pen and clean more thoroughly. To reset for a given thickness draw a short length on a scrap of paper and lay it alonside of a line of the desired thickness, previously drawn. The difference will be seen, the pen can be changed and another trial made, and so on until the lines are matched.

For ruled lines the ruler or curve is laid in the proper position and the pen drawn along the edge, lightly pressing against it. The pen should be held with the plane of its points perpendicular to the plane of the paper and in the direction of motion. The handle should be slightly inclined in the same direction. For free-hand lines, as contours, hold the pen in the same way and move the hand so as to cause the points to follow the line.

In ruling with a writing pen choose one of a size which will make a line of the required thickness without pressing on the paper. Dip the point only in the ink. If the ruler has a beveled edge place it with the top projecting. A curve or a ruler not beveled should be raised slightly from the paper. The pen should not be inked above the point which touches the ruler. It is held as described for the ruling pen. Parallel lines close together may be drawn with one setting of the ruler by inclining the pen slightly.

Writing pens are best for stream lines. When it can be done, vary the size of the pen to suit the thickness of line. When using a writing pen free-hand do as much of the work as possible by drawing the pen toward the body in about the direction of the down stroke in writing.

For lettering, signs, and all free-hand work with the writing pen, keep the pen clean and freshly inked and the ink free from dust and of proper consistency to flow freely without dripping from the pen in blots.

In using a circular pen (fig. 43), set the legs of the compasses so that they will span the right distance and the pen point will be vertical. The lead of a pencil point should be sharpened to the shape of the ruling-pen points with the flat side toward the pivot leg of the compasses. When using compasses with pen or pencil, incline them slightly in the direction of motion and rotate the head between the thumb and forefinger. Very slight pressure only should be necessary beyond the weight of the instrument.

Figure 40 represents the most convenient instrument for measuring the length of curved or broken lines on a map. The small wheel is run over the line, and its length in the unit of the instrument is read from the dial. This length is converted into actual length by the scale of the map.

92. **Papers.**—Manila paper of cream or buff tint, usually called **detail paper,** is suitable for sketches and drawings which are to be traced or used in the field. Only the better grade stands erasing and that imperfectly. This paper comes in rolls 36, 42, and 54 inches wide. It may be ordered by the pound or yard.

White drawing paper may be had in rolls or sheets mounted on muslin or unmounted. Whatman's cold-pressed fine-grain is most generally useful. It comes in sheets of names and sizes as follows: Royal, 19 by 24 inches; Imperial, 22 by 30 inches; Double Elephant, 27 by 40 inches; Antiquarian, 31 by 53 inches. Roll papers are 27 to 63 inches wide.

Sheet papers unmounted and kept flat are best for field topographical use.

WORKS AND STRUCTURES

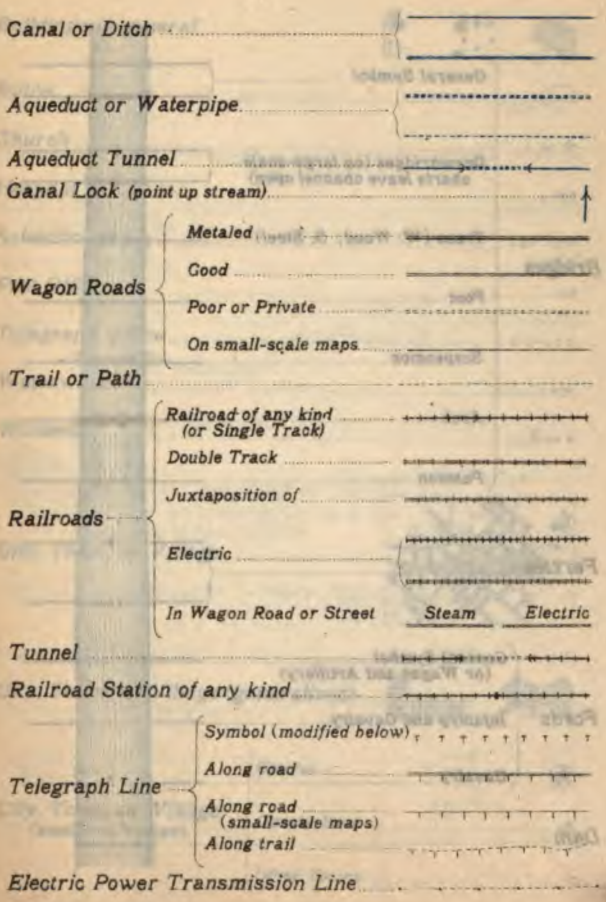


Fig. 48

WORKS AND STRUCTURES

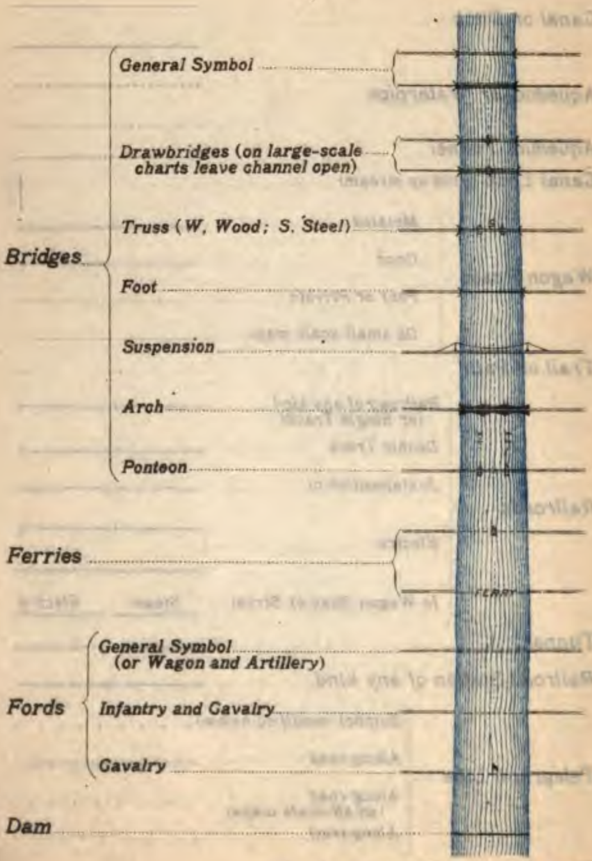

Bridges
General Symbol
Drawbridges (on large-scale charts leave channel open)
Truss (W, Wood; S, Steel)
W
S
Foot
Suspension
Arch
Ponteon
Ferries
FERRY
Fords
General Symbol (or Wagon and Artillery)
Infantry and Cavalry
Cavalry
Dam

Fig. 49

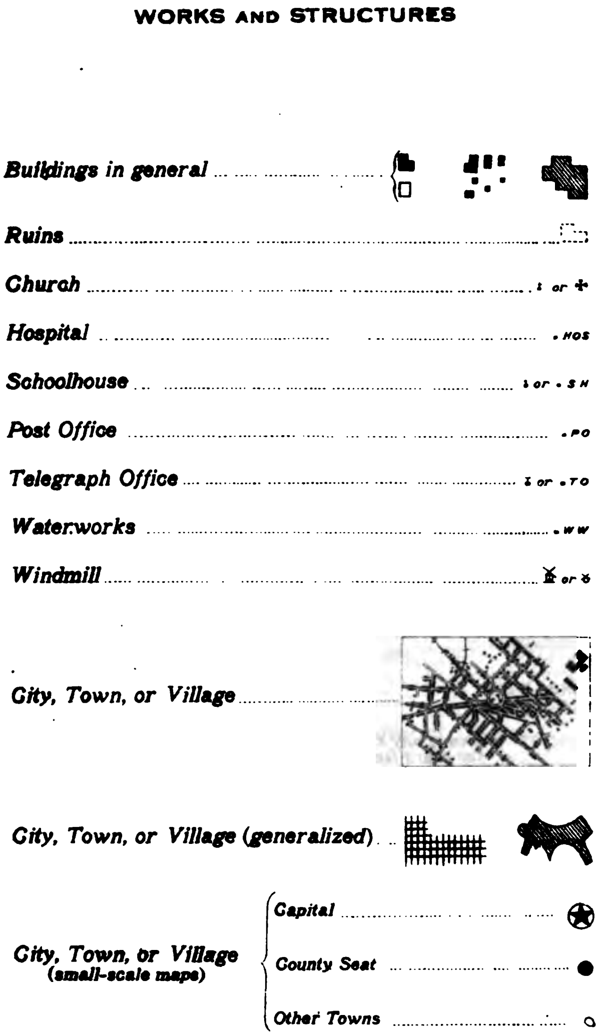

WORKS AND STRUCTURES
Buildings in general
Ruins
Church
or
Hospital
HOS
Schoolhouse
or
SH
Post Office
PO
Telegraph Office
or
TO
Waterworks
WW
Windmill
or
City, Town, or Village
City, Town, or Village (generalized)
City, Town, or Village (small-scale maps)
Capital
County Seat
Other Towns

Fig. 50

WORKS AND STRUCTURES

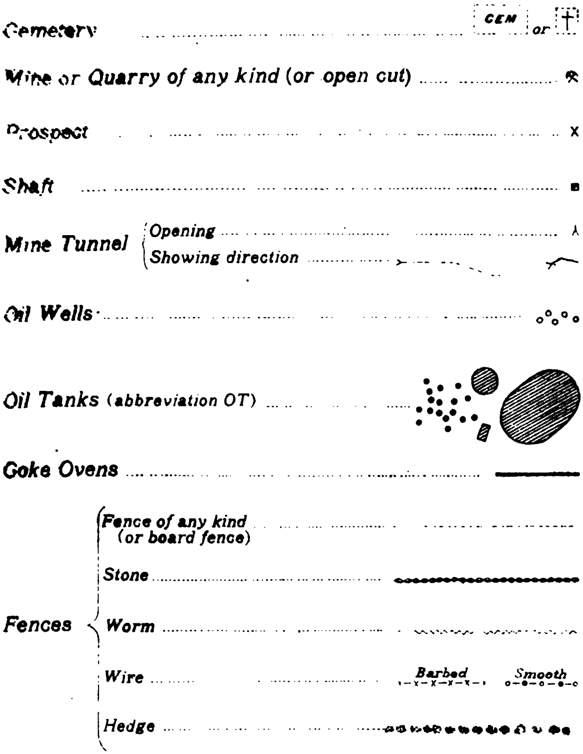


Fig. 51

BOUNDARIES, MARKS AND MONUMENTS

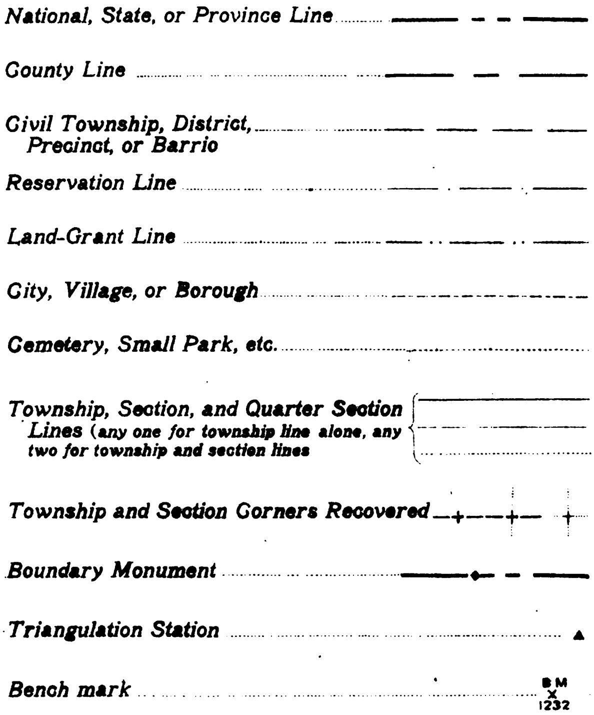
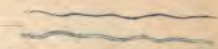

National, State, or Province Line
County Line
Civil Township, District, Precinct, or Barrio
Reservation Line
Land-Grant Line
City, Village, or Borough
Cemetery, Small Park, etc.
Township, Section, and Quarter Section Lines (any one for township line alone, any two for township and section lines
Township and Section Corners Recovered
Boundary Monument
Triangulation Station
Bench mark
BM
x
1232
U. S. Mineral Monument

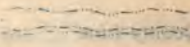
Fig 52

DRAINAGE

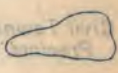
Streams in general ....



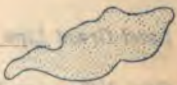
Intermittent Streams ....



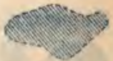
Lake or Pond in general ....
(*with or without tint, waterlining, etc.*)



Salt Pond (*broken shoreline if intermittent*) ....

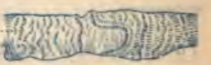


Intermittent Lake or Pond ....

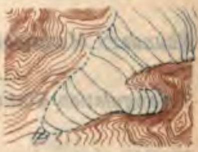


Spring ....

Falls and Rapids ....



Glaciers
- *Contours* (*or as below*) ....



- *Form Lines showing flow* ....

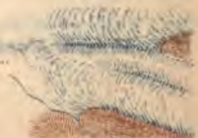


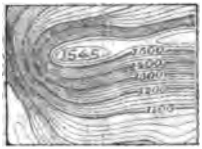
Fig. 53

RELIEF

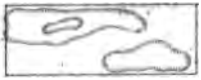
(Shown by contours, form lines, or shading as desired)

Hill Shapes .... *Form lines, hachures, stipple, or other shading*

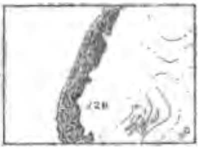
Contour System ....



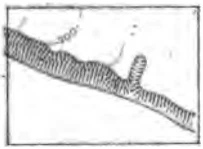
Depression Contours, if otherwise ambiguous, hachured thus ....



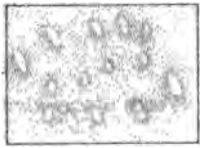
Bluffs
- ***Rocky (or use contours)*** ....



- ***Other than rocky (or use contours)*** ....



Sand Dunes ....



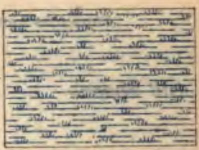
Levee ....

Fig 54

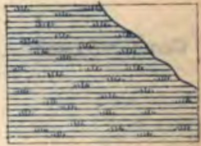
LAND CLASSIFICATION

Marsh

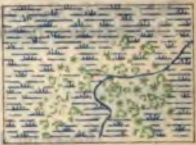
- ***Marsh in general*** **(*or Fresh Marsh*)** ......



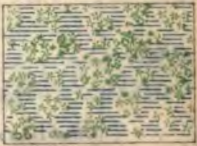
- ***Salt*** ......



- ***Wooded*** ......



- ***Cypress Swamp*** ......



Woods of any kind **(*or as shown below*)** ...... 🟩

Woods of any kind **(*or Broad-Leaved Trees*)**

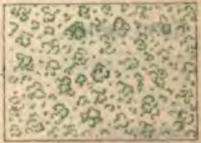


Fig. 55

LAND CLASSIFICATION

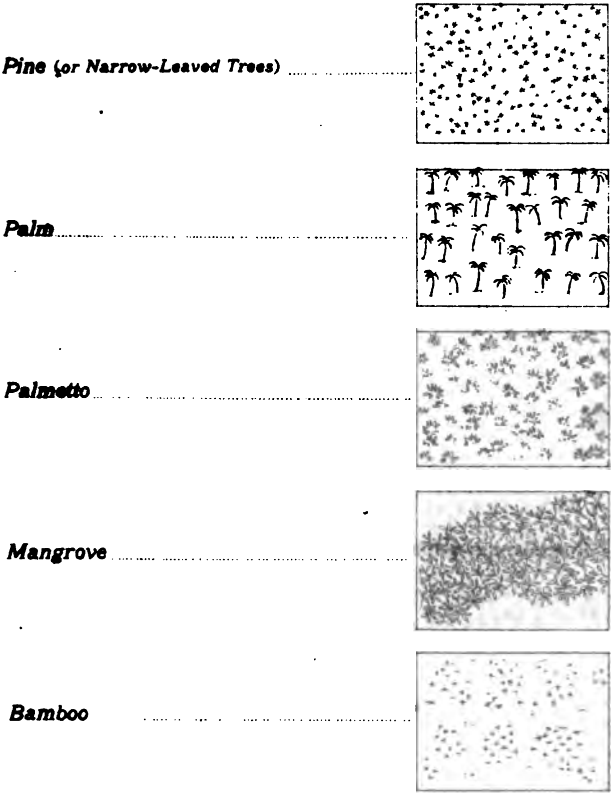


Fig. 56

LAND CLASSIFICATION

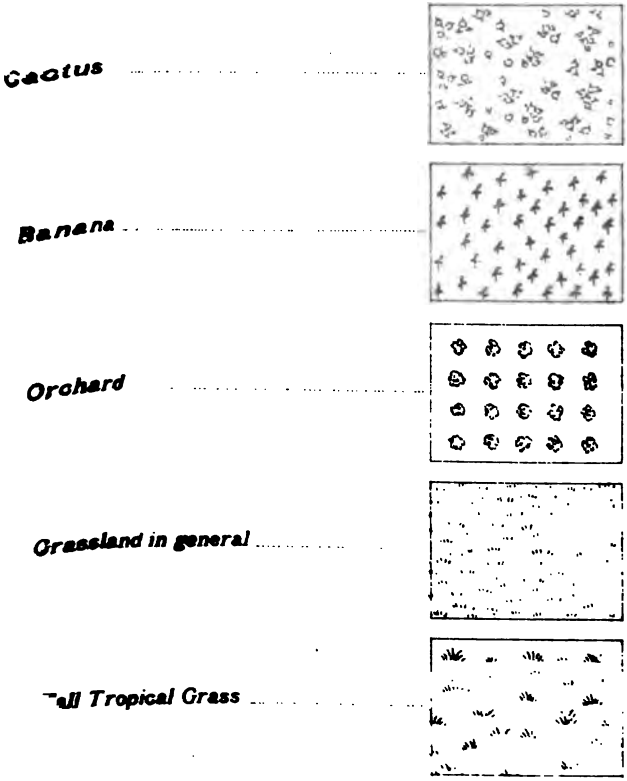


Fig. 37

LAND CLASSIFICATION

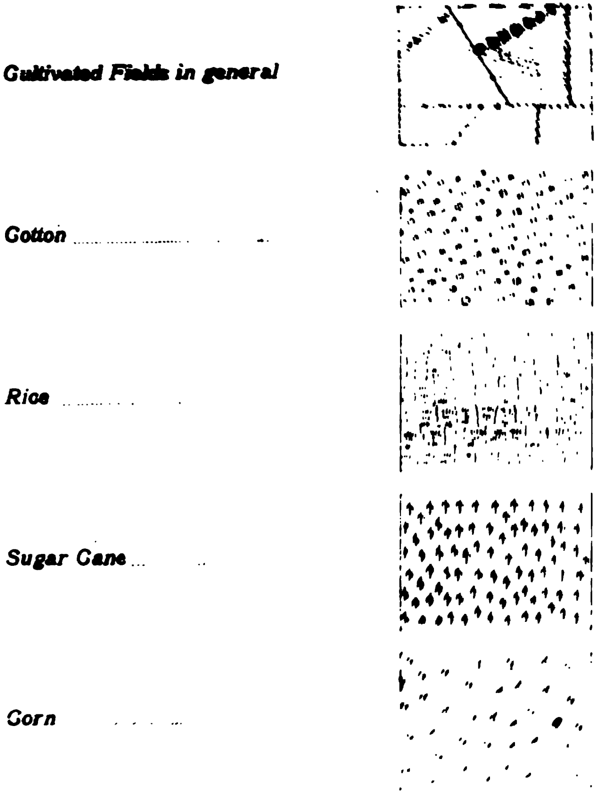


Fig. [illegible]

HYDROGRAPHY, DANGERS OBSTRUCTIONS

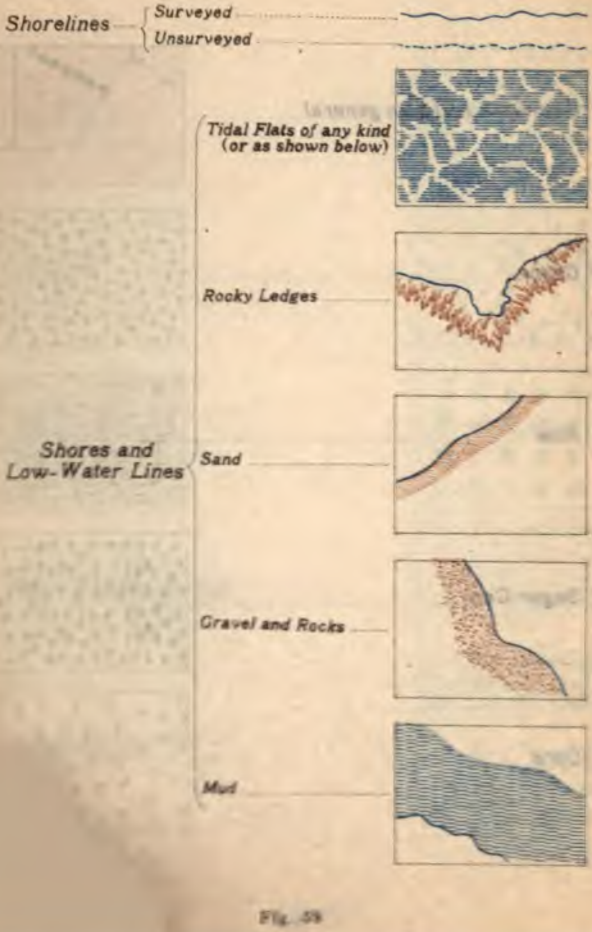


Fig. 58

HYDROGRAPHY, DANGERS, OBSTRUCTIONS

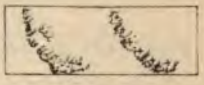
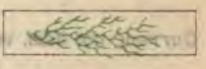
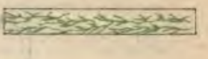
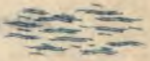
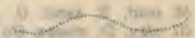
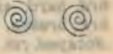
Coral Reefs	
Kelp	
Eel Grass	
Rock under water	+ ⊛
Rock awash (at any stage of the tide)	* ⊛
Rock whose position is doubtful	⊛ *PD*
Rock whose existence is doubtful	⊛ *ED*
Overfalls and Tide Rips	
Limiting Danger Line	
Whirlpools and Eddies	
Wreck of any kind (or Submerged Derelict)	+++
Wreck or Derelict not submerged	
Cable (with or without lettering)	- - - - - - - - - - -

Fig. 60

HYDROGRAPHY, DANGERS, OBSTRUCTIONS

Current, not tidal, velocity 2 knots .... 2 kn →

Tidal Currents
- *Flood, 1½ knots* .... 1½ kn →
- *Ebb, 1 knot* .... 1 kn →
- *Flood, 2d hour* .... → or →
- *Ebb, 3d hour* .... → or →

No bottom at 50 Fathoms .... $\overset{+}{50}$ $\overset{\bullet}{50}$

Abbreviations relating to Bottoms

***M.** mud, **S.** sand, **G.** gravel, **Sh.** Shells, **P.** pebbles, **Sp.** specks, **Cl.** clay, **St.** stones, **Co.** coral, **Oz.** ooze, **bk.** black, **wh.** white, **rd.** red, **yl.** yellow, **gy.** gray, **bu.** blue, **dk.** dark, **lt.** light, **gn.** green, **br.** brown, **hrd.** hard, **sft.** soft, **fne.** fine, **crs.** coarse, **rky.** rocky, **stk.** sticky, **brk.** broken, **lrg.** large, **sml.** small, **stf.** stiff, **cal.** calcareous, **dec.** decayed, **rot.** rotten, **spk.** speckled, **fly.** flinty, **gty.** gritty, **grd.** ground, **str.** streaky, **vol.** volcanic.*

Fig. 61

HYDROGRAPHY, DANGERS, OBSTRUCTIONS

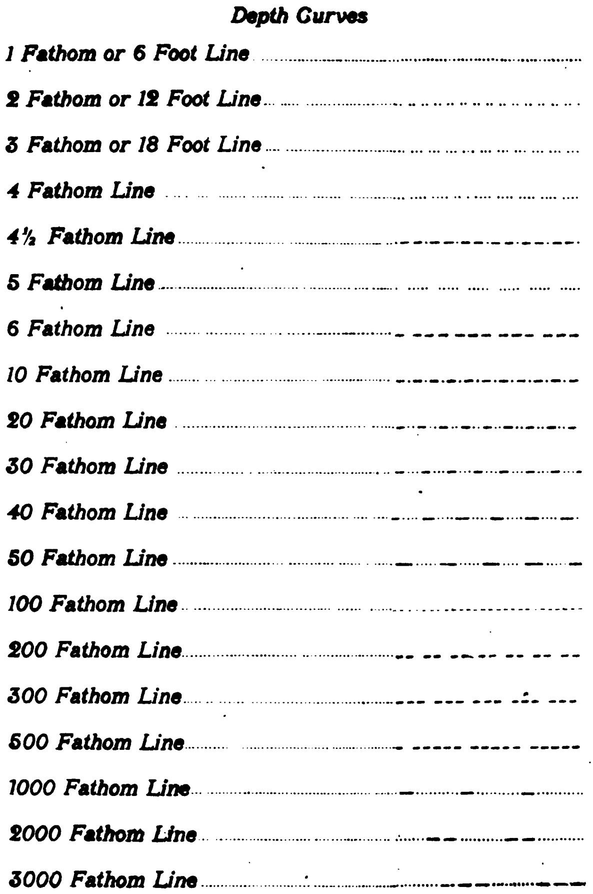
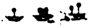
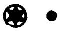
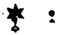
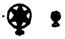
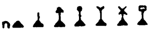


Fig. 62

AIDS TO NAVIGATION, ETC.

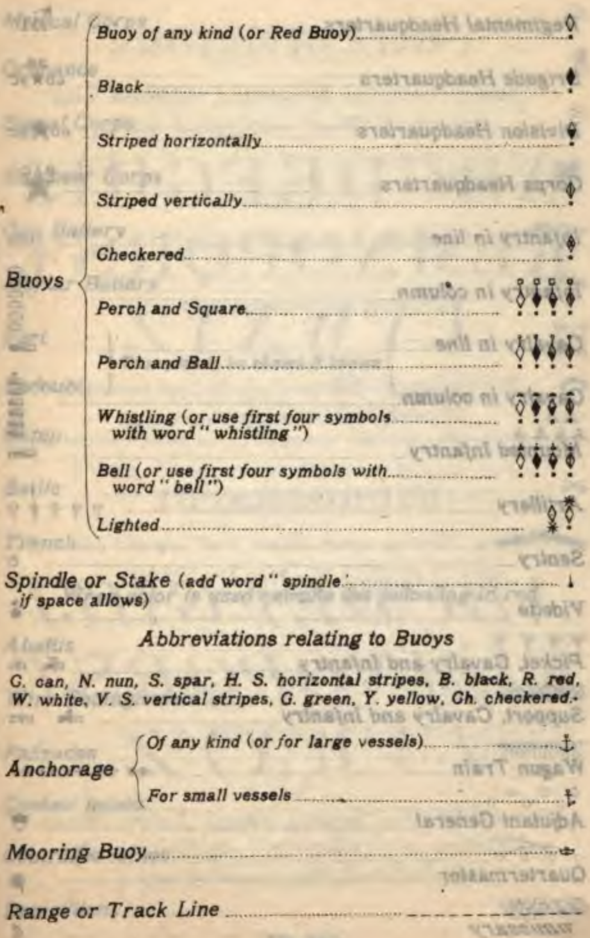
Life-saving Station [(T) *indicates telegraphic connection*]		L.S.S (T)
Light of any kind (or Lighthouse)		
Lighthouse, on small scale chart		•
Light Vessel of any kind		
Light Vessels showing number of masts		
Light with Wireless		
Light Vessel with Wireless		
Light with Submarine Bell		
Light Vessel with Submarine Bell		
Light with Submarine Bell and Wireless		
Light Vessel with Submarine Bell and Wireless		
Beacons	*Lighted*	
	Not lighted	Bn 

Sectors, shown by dotted lines

Abbreviations relating to Lights

fixed, Fig. *flashing*, Fl. *flash*, Fls. *flashes*, Sec. *sector*, Rev. *revolv-*
E. *electric*, W. *white*, R. *red*, V. *varied by*, Grp. *group*, Occ.
lting, Int. *intermittent*, Alt. *alternating*, m. *miles*, min. *minutes*,
econds.

AIDS TO NAVIGATION, ETC.


Buoys
Buoy of any kind (or Red Buoy)
Black
Striped horizontally
Striped vertically
Checkered
Perch and Square
Perch and Ball
Whistling (or use first four symbols with word "whistling")
Bell (or use first four symbols with word "bell")
Lighted
Spindle or Stake (add word "spindle" if space allows)
Anchorage
Of any kind (or for large vessels)
For small vessels
Mooring Buoy
Range or Track Line

Abbreviations relating to Buoys

G. can, N. nun, S. spar, H. S. horizontal stripes, B. black, R. red, W. white, V. S. vertical stripes, G. green, Y. yellow, Ch. checkered.

Fig. 64

SPECIAL MILITARY SYMBOLS

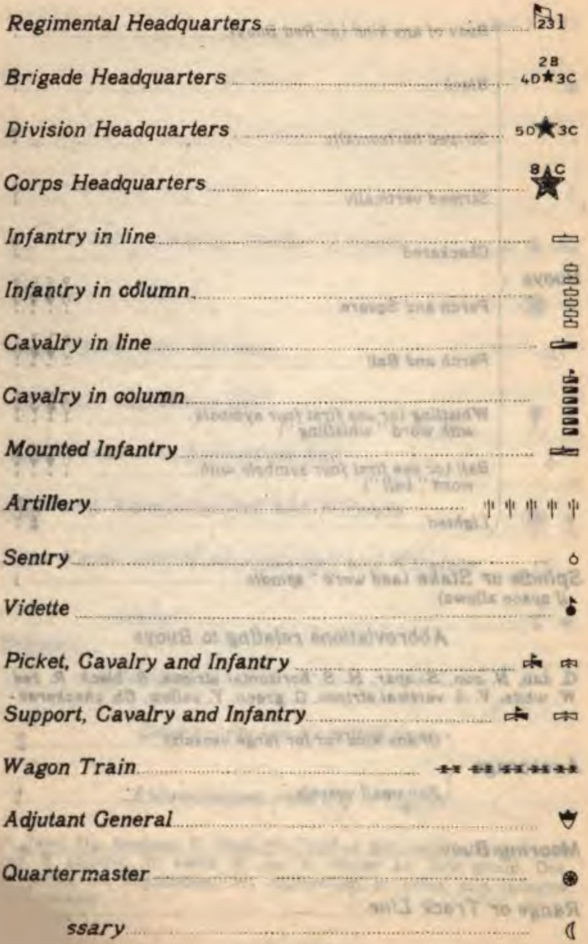
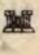
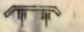
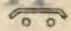
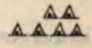
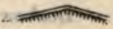


Fig. 65

SPECIAL MILITARY SYMBOLS

Medical Corps	
Ordnance	
Signal Corps	
Engineer Corps	
Gun Battery	
Mortar Battery	
Fort	
Redoubt	
Camp	
Battle	
Trench	

Fort, *Redoubt*: *True plan to be shown if known*

When color is used execute the following in red

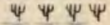
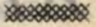
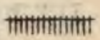
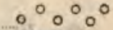
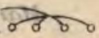
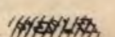
Abattis	
Wire Entanglement	
Palisades	
Contact mines	
Controlled mines	
Demolitions	

Fig. 65 a

CIVIL DIVISIONS

States, Counties, Townships, Capitals and Principal Cities (all capital letters)

ABCDEFGHIJ
KLMNOPQRST
UVWXYZ

Towns and Villages (with Cap. initials)
abcdefghijklmnopqrstuvwxyz

HYDROGRAPHY

Lakes, Rivers and Bays (all capital letters)

ABCDEFGHIJ
KLMNOPQRST
UVWXYZ

Brooks, Springs, small Lakes, Ponds,
es and Glaciers (with Cap. initials)
lefghijklmnopqrstuvwxyz

Fig. 66

HYPSOGRAPHY

Mountains, Plateaus, Lines of Cliffs
and Canyons (all capital letters)

ABCDEFGHIJKLMNOPQRSTU
VWXYZ

Peaks, small Valleys, Canyons, Islands and Points.
(with Cap. initials)

abcdefghijklmnopqrstuvwxyz

PUBLIC WORKS

Railroads, Tunnels, Bridges, Ferries, Wagon-roads,
Trails, Fords and Dams (capitals only)

ABCDEFGHIJKLMNOPQRSTUVWXYZ

CONTOUR NUMBERS

1234567890 *1234567890*

MARGINAL LETTERING

ABCDEFGHIJKLMNOPQRSTU
VWXYZ

(with Cap. initials)

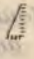
abcdefghijklmnopqrstuvwxyz
1234567890

Fig. 66 a

LETTERING

Names of natural land features, vertical lettering
Names of natural water features, slanting lettering

Thickness of letter $\frac{1}{7}$ of height
Slope of letter 3 parts of base to 8 of height



AUTHORIZED ABBREVIATIONS

A.	Arroyo	L.S.S.	Life Saving Station
abut.	Abutment	L.H.	Lighthouse
A.	Arch	Long.	Longitude
b.	Brick	Mt.	Mountain
B.S.	Blacksmith Shop	Mts.	Mountains
bot.	Bottom	N.	North
Br.	Branch	n.f.	Not fordable
br.	Bridge	p.	Pier
C.	Cape	pk.	Plank
cem.	Cemetery	P.O.	Post Office
con.	Concrete	Pt.	Point
cov.	Covered	q.p.	Queen-post
Cr.	Creek	R.	River
cul.	Culvert	R.H.	Roundhouse
D.S.	Drug Store	R.R.	Railroad
E.	East	S.	South
Est.	Estuary	s.	Steel
f.	Fordable	S.H.	School House
Ft.	Fort	S.M.	Saw Mill
G.S.	General Store	Sta.	Station
gir.	Girder	st.	Stone
G.M.	Grist Mill	str.	Stream
i.	Iron	T.G.	Toll Gate
I.	Island	Tres.	Trestle
Jc.	Junction	tr.	Truss
k.p.	King-post	W.T.	Water Tank
	Lake	W.W.	Waterworks
	Latitude	W.	West
	Landing	w.	Wood

Fig. 67

93. If a blot drops on the drawing take a piece of blotting paper, tear a corner or edge to expose a fresh surface, and hold it in the blot without touching the drawing until the surplus ink is absorbed. Then press a dry blotter firmly on the spot and let it dry thoroughly before attempting to erase. A piece of newspaper may be used instead of blotting paper, but should be slightly moistened to hasten the absorption. For a large plot several pieces may be required.

94. **Erasers** for ink are of steel or rubber. A steel eraser or penknife must be very sharp to give good results. An eraser of gritty rubber is most generally used. It is best to use an erasing shield of thin metal or celluloid (fig. 44), which exposes the area to be erased through one of the openings and protects the rest.

95. **Tracing linen** is usually *dull back*, having one side glazed and the other dull. Erasing can be done on the glazed side only. The glazed side is used for ink and the dull side for pencil work. The glazed side requires preparation before use to remove excess of paraffin, which prevents ink from running well and clogs the pen. Rubbing hard with fresh blotting paper is the simplest method.

Tracing paper is alike on both sides. It will not erase. Most varieties are less transparent than tracing cloth.

In tracing it is helpful to use a dull-painted instrument in the left hand—a stylus or top of a penholder—to press the linen against the drawing at the point where the pen is resting.

96. **Conventional signs.**—The symbols or signs used to represent topographical features are designed to be rapidly made and readily understood, and to resemble or suggest the actual features they represent. Multiplicity of signs is not desirable, and a verbal designation or description of the features is often more intelligible and more quickly recorded. For instance, it is better to write the names of the growing crops of a district, as tobacco, corn, or cane, than to cover the entire area with a symbol. Another method of expediting mapping is to surround an area with a narrow border of the proper sign and leave the middle blank.

The conventional signs adopted in 1912 and published to the Army in pamphlet form are shown in figures 48 to 67, inclusive.

The adaptation of conventional signs to the size and scale of the map is accomplished in part by varying the boldness of the pen or brush strokes and in part by wider spacing of them. The strokes must never be so small as to render the sign illegible and never larger than can be easily made with a medium pen. The object is to produce a result which, while distinct as to conventional meaning, shall not be so heavy in general tone as to catch the eye, or, what is especially important in military maps, to obscure any additions which may be made. Topographical signs should be perfectly clear when looked for, but not obtrusive.

As a rough guide, it may be stated that the signs shown in the plates are about right for continuous areas of 3 square inches or less in maps of scales of 2 or 3 inches to the mile. If the map areas are larger or the scale smaller, the signs should be lightened some, but not much, by making the strokes smaller and by spacing them wider. Some examples of good maps show the meadow sign, for example, with two or three elements to the square inch. For very large scale maps and for field sketches the strokes may be made heavier and the spacing in them close. These remarks apply only to cultural signs, and a few others the significance of which is independent of size and shape. All natural or artificial features in which size and form are in any way material should be drawn with as much regard to the scale as practicable. This becomes more important as the scale is larger.

It may, therefore, happen that the same feature will be differently shown on maps of different scales. This is well illustrated in the case of streams. Figure 53 shows four signs for streams. On a large-scale map, say 1 : 1,000, a rivulet a few feet wide would be shown by the second sign, while on a scale of 1 : 1,000,000 a stream 1 mile wide would be shown by the first sign.

[illegible]

Titles, notes, etc. [illegible] and drawing should have a [illegible]

[illegible] under whose [illegible] it is made, as *Engineer Department; Bureau of Insular Affairs; War Department; Division of the Philippines; 1st Division, 2d Corps.*

(2) [illegible] as **map, sketch, plot, plan, profile, section, or elevation.** If more than one kind of drawing appears on the sheet, each should be mentioned in the title, as **plan and sections of battery; Plan, section, and elevations of guardhouse,** etc.

(3) Its subject, if it relates to a particular object, feature, or purpose.

(4) Its locality. This and the preceding may be interchanged in position.

(5) Its sources, as **Compiled from, etc.; Reduced from, etc.; From a survey, etc.**

(6) Its authorship. If the work has been done by one person, acting under the instructions of another, both should be named, as *under the direction of Colonel* **John Doe,** *General Staff,* by *Captain* **William Roe,** *1st U. S. Infantry.*

(7) Its date.

(8) Its linear scale; its contour interval; its scale of slope equivalents.

Titles should be adapted in size and boldness to the size and importance of the sheet. They should be divided into lines, following mainly the divisions just stated. The middle letter of each line should fall on a line drawn vertically through the middle of the space allotted to the title. Lines should be alternately long and short, and if the long lines are symmetrically disposed, the effect is better.

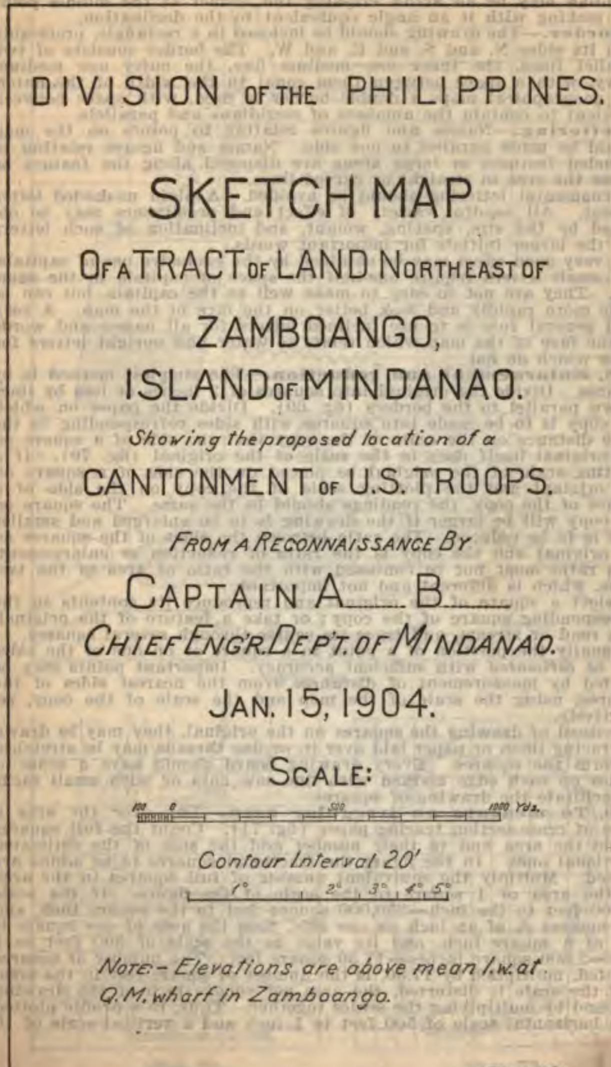
To prepare a title, write down the matter under the various heads, with proper connecting words, and divide it up into lines. Then block out the title, observing the division of lines decided upon, and make such alterations as seem desirable. Finally, letter the title on the map. The following is an example:

Division of the Philippines. | Sketch map | of a tract of land northeast of | Zamboanga, | Island of Mindanao, | showing the proposed location of a | cantonment of U. S. troops. | From a reconnaissance by | Capt. A____ B. __, | Chief Engr., Department of Mindanao, | Jan. 15, 1904. | Scale. | Contour interval, 20 ft.

Notes. Besides the title, such information as will help to a proper understanding of the meaning and value of the map should be given in the form of notes. These usually relate to methods used in the survey, datum points, etc.

Figure 68 shows the title corresponding to the above example, with notes.

Meridian.— The magnetic meridian should be shown, and the true an also if the declination is known. The true meridian may e, of 3 inches or upward in length, with a star at its north feather of an arrow at its south end. The magnetic



DIVISION OF THE PHILIPPINES.

SKETCH MAP

OF A TRACT OF LAND NORTHEAST OF

ZAMBOANGO,

ISLAND OF MINDANAO.

Showing the proposed location of a

CANTONMENT OF U.S. TROOPS.

FROM A RECONNAISSANCE BY

CAPTAIN A___ B___

CHIEF ENG'R. DEP'T. OF MINDANAO.

JAN. 15, 1904.

SCALE:

100
0
500
1000 Yds.

Contour Interval 20'

1°
2°
3°
4°
5°

NOTE: – Elevations are above mean l.w. at Q.M. wharf in Zamboango.

Fig. 68.

meridian may be an arrow crossing the former at the middle point and making with it an angle equivalent to the declination.

Border.—The drawing should be inclosed in a rectangle, preferably with its sides N. and S. and E. and W. The border consists of two parallel lines, the inner one medium fine, the outer one medium heavy, with a space between them equal to the width of the outer. For geographical maps a double border is used, with space between sufficient to contain the numbers of meridians and parallels.

Lettering.—Names and figures relating to points on the map should be made parallel to one side. Names and figures relating to extended features or large areas are disposed along the feature or across the area in straight or curved lines.

Ornamental lettering should be avoided. A plain unshaded letter is best. All needful variety of effect and prominence may be obtained by the size, spacing, weight, and inclination of such letters and the larger initials for important words.

A very good effect may be obtained by the exclusive use of capitals. The small letters require one-half the space of capitals in the same line. They are not so easy to make well as the capitals, but can be made more rapidly and look better on the face of the map. A very good general rule is to use inclined letters for all names and words on the face of the map which relate to water and upright letters for those which do not.

98. **Enlargement and reduction.**—The simplest method is by squares. Divide the original into squares of 2 inches or less by lines drawn parallel to the borders (fig. 69). Divide the paper on which the copy is to be made into squares with sides corresponding to the same distance on the scale of the copy that the side of a square on the original itself does to the scale of the original (fig. 70). If a plotting scale of the original be placed on the side of a square on the original and the plotting scale of the copy on the side of a square of the copy, the readings should be the same. The square on the copy will be larger if the drawing is to be enlarged and smaller if it is to be reduced. The ratio between the sides of the squares on the original and the copy is the ratio of reduction or enlargement. This ratio must not be confused with the ratio of area of the two maps, which is different and not important.

Select a square of the original and reproduce its contents in the corresponding square of the copy; or take a feature of the original, as a road or stream, and trace its course through several squares.

Usually the position of a point in a square or on one of the sides can be *estimated* with sufficient accuracy. Important points may be located by measurement of distances from the nearest sides of the squares, using the scale of the map and the scale of the copy, respectively.

Instead of drawing the squares on the original, they may be drawn on tracing linen or paper laid over it, or fine threads may be stretched to form the squares. Every drawing board should have a scale of inches on each edge marked with fine saw cuts or with small tacks to facilitate the drawing of squares.

99. **To measure an irregular area.**—Lay over the area a piece of cross-section tracing paper (fig. 71). Count the full squares inside the area and to their number add the sum of the estimated fractional ones. In the figure the fractional squares to be added are shaded. Multiply the equivalent number of full squares in the area by the area of 1 square to the scale of the figure. If the scale is 500 feet to the inch=250,000 square feet to the square inch, and the squares $\frac{1}{12}$ of an inch on one side, then the area of one square is 1 of a square inch, and its value to the scale of 500 feet to 1 -9,500 square inches=17.36 square feet. The number of squares multiplied by 17.36, is the number of square feet in the area. scale is distorted, the area per square inch of the drawing multiplying the scales together. Thus, in a profile plotted l scale of 500 feet to 1 inch and a vertical scale of 10

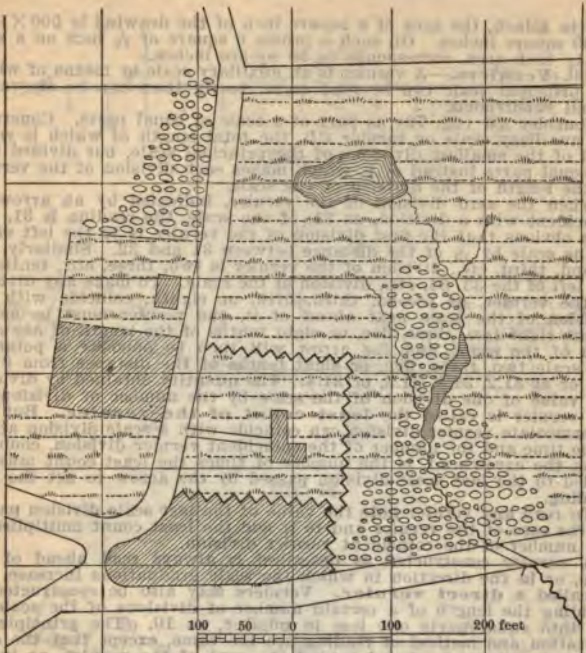


Fig. 69

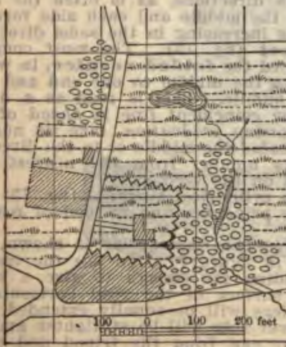


Fig. 70

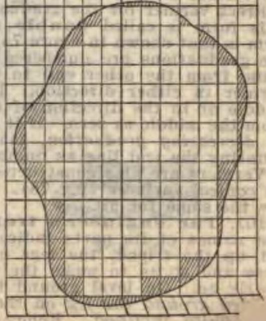


Fig. 71

feet to 1 inch, the area of a square inch of the drawing is $500 \times 10 = 5,000$ square inches. On such a profile a square of $\frac{1}{10}$ inch on a side, or $\frac{1}{100}$ inch area, corresponds to 50 square inches.

100. **Verniers.**—A vernier is an auxiliary scale by means of which the principal scale can be read more closely than can be shown by actual subdivision.

Consider *AB* (fig. 72) as part of a scale of equal parts. Construct the auxiliary scale or vernier *CD*, the total length of which is equal to 9 of the smallest divisions of the principal scale, but divided into 10 equal parts instead of 9, which makes each division of the vernier $\frac{9}{10}$ the length of the division of the scale.

When the zero division of the vernier, indicated by an arrow, is coincident with a division, as 31, of the scale, the reading is 31, and it is obvious that the first division of the vernier is to the left of 32 in the scale by $\frac{1}{10}$ of the distance between 31 and 32. Similarly, the second, third, etc., division of the vernier is two, three, etc., tenths to the left of the 33, 34, etc., division of the scale. To make any division of the vernier, as second, third, fifth, or eighth, coincide with the division of the scale next ahead of it, the vernier must be moved to the right two, three, five, or eight tenths of the length of one division of the scale, and the arrow will then be opposite a point on the scale two, three, five, or eight tenths of the distance from 31 to 32; or at 31.2, 31.3, 31.5, or 31.8. The quantity obtained by dividing the value of one division of the scale by the number of divisions of the vernier is called the **least count of the vernier.** But one intermediate vernier division can coincide with a scale division at the same time and the number of the coincident vernier division, counting from the arrowhead, is the number of times the least count must be added to the last scale division passed by the arrow to get the true reading.

To read any vernier note the value of the last scale division passed by the zero of the vernier and to it add the least count multiplied by the number of the coincident vernier division.

A vernier constructed as described is always read ahead of the zero, or in the direction in which the scale graduations increase, and is called a **direct vernier.** Verniers may also be constructed by dividing the length of a certain number of divisions of the scale, as 11, into equal parts one less in number, as 10. The principles of operation and method of reading are the same, except that the coincident line is to be found behind the zero of the vernier, or in the direction in which scale graduations decrease. This form is called **retrograde.** It is but little used.

If the scale is graduated in both directions, as is often the case, the vernier is doubled, the zero in the middle and each side forming a direct vernier for the graduations increasing in the same direction. This form is called **double direct** (fig. 73). The most compact form is that shown in figure 74, called the **folded vernier,** in which the graduations are numbered from the middle to one end and continue from the other end to the middle. This is read as a direct vernier in either direction. If the coincident line is *ahead* of the middle or in the direction of *increasing graduation,* take its number from the middle as zero. If it is *behind* the middle or in the direction of *decreasing graduation,* take its number from the nearest end, counting the end line as numbered on the vernier.

Verniers are also constructed on cylindrical surfaces (fig. 75) and on conical surfaces (fig. 76). The principles and method of reading are the same for all.

101. **The engineer's transit.**—This instrument is shown, and the names of its parts indicated in figure 77. To use the transit, p the tripod, the legs extending far enough to give a stable nd so as to make the top surface of the head horizontal or so. On level ground the legs will be equally extended. On ground the leg on the lower side will be straighter and the e inclined. Remove the cap from the tripod and screw ument in its place. Hang the plumb line on the hook

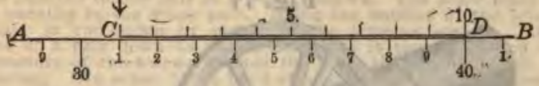


Fig. 72

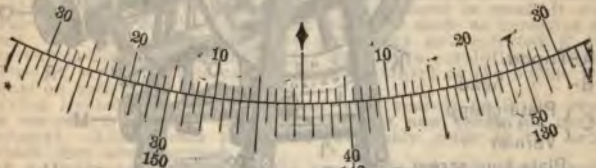


Fig. 73

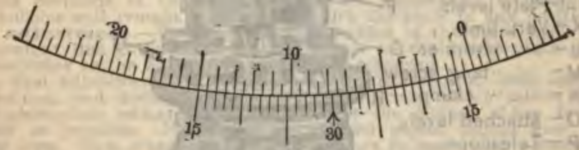


Fig. 74

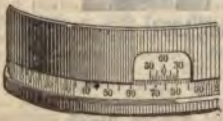


Fig. 75

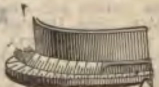
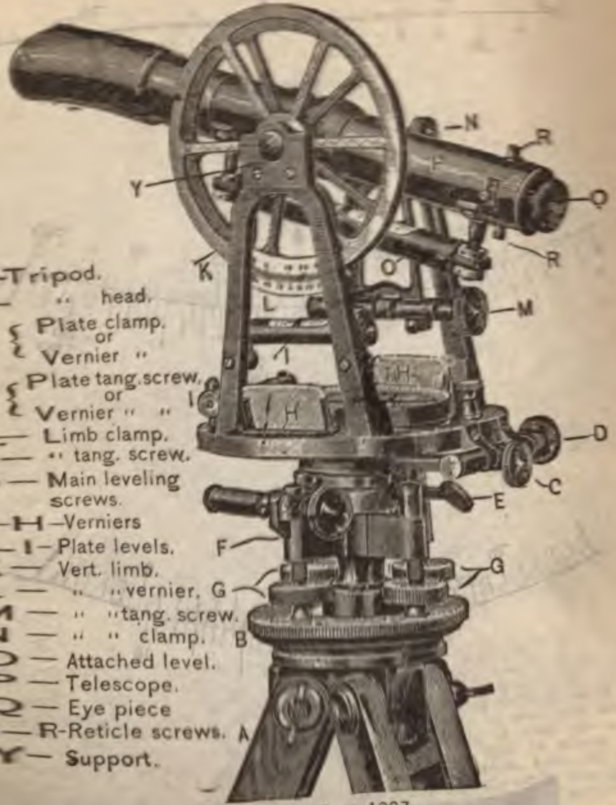


Fig. 76

Fig. 77



A—Tripod.
B— " head.
C { Plate clamp. or Vernier "
D { Plate tang. screw, or Vernier " "
E— Limb clamp.
F— " tang. screw.
G— Main leveling screws.
H—H—Verniers
I—I—Plate levels.
K— Vert. limb.
L— " " vernier.
M— " " tang. screw.
N— " " clamp.
O— Attached level.
P— Telescope.
Q— Eye piece
R—R-Reticle screws.
Y— Support.

Addendum, 1907

depending through the tripod head, and adjust its length to bring the point of the plumb bob as close as possible to the setting point. Unclamp the vernier and turn the transit so that one of the plate levels is parallel to one pair of leveling screws. The other plate level will be parallel to the other pair. Bring the bubbles of the levels to the center in succession by means of the leveling screws. Always turn one of a pair down as the opposite one is turned up and avoid more pressure of the screws against the plate than is necessary for a firm bearing. If a screw turns hard at any time it is either sprung or has been set up too tight. In turning a pair of leveling screws always move the thumbs toward each other or away from each other. The bubble will follow the motion of the left thumb.

With the level bubbles in the centers of their tubes the plate will be level if the bubbles are in adjustment. Turn the transit slowly in azimuth and watch the bubbles. If they remain in the centers the plate is level and the levels are also correct. If either bubble leaves the center, the amount of its motion indicates the amount by which it is out of adjustment. If the amount is small it may be neglected; if large, the adjustment should be made as hereafter described. For short lines the level error may be neglected if the entire bubble remains in sight during the entire revolution. Adjust the leveling screws in this case so that the travel of the bubble will be equal on both sides of the center.

Having leveled the plate, draw out the eyepiece until the cross hairs are clearly defined. The instrument is now ready for use or adjustment. Adjustments should be invariably made in the order in which they are described.

1st adjustment.—To make the axes of the plate levels perpendicular to the axis of the instrument and therefore parallel to the plate:

Having set up and leveled clamp the limb and revolve the plate 180°. If either bubble recedes from the middle of its tube bring it back by raising the lower or depressing the higher end, one-half by the main leveling screws and one-half by the small screws which fasten the level to the plate. Again revolve the plate 180°, and if the bubble still recedes from the middle correct the error as before and repeat the operation until the bubble does remain in the middle in both positions of the plate. When the adjustment is complete both bubbles will remain in the center with the plate in any position.

2d adjustment.—To place the intersection of the cross wires in the straight line through the optical center of the object glass and perpendicular to the horizontal axis of the telescope.

The first adjustment completed, direct the telescope to some small, well-defined, and distant object. With the screw which moves the object-glass slide adjust the latter so that the distant object is as distinct as possible. Both cross wires and object should now be clearly seen. Note whether the image appears to move with reference to the wires when the eye is moved from side to side across the opening of the eyepiece. Such displacement is called **parallax**, and indicates that the image is not exactly in the plane of the cross wires. Move the object glass by its thumbscrew until the parallax ceases. **This must be done every time the transit is used** to read an angle, as well as when adjusting it.

Unclamp the plate and lay the intersection of the wires upon the middle of a pin 200 or 300 feet distant; clamp the plate; plunge the telescope, that is, revolve it about its horizontal axis, and have a pin driven at the same distance from the transit so that its middle shall be seen exactly at the intersection of the cross wires. Revolve the plate 180°, clamp and lay exactly upon the middle of the first pin. Again plunge the telescope and look at the second pin. If the intersection again strikes the pin the adjustment is correct, but if the pin appears to one side of the intersection bring it back one-quarter of the way by the side reticle screws, turning one in as the other is turned out. If the instrument is *erecting* (most transits are) loosen the reticle screw on the side toward which the wire should move in the field and tighten the other one. If *inverting*, turn the other way. Repeat the process until the pins are cut exactly in the middle without reference to position of transit or telescope. The adjustment will then be correct.

3d adjustment.—To make the horizontal axis of the telescope perpendicular to the vertical axis of the instrument:

The instrument leveled, lay the telescope on a point at the top of a nearly vertical line, such as the corner of a building or a steady plumb line. Clamp the plate and depress the telescope until the horizontal wire is near the lower end of the vertical line and note the position of the intersection of the wires with respect to the selected vertical, whether to right or left of it, and how much. Revolve the plate 180°; on the top point of the selected vertical; again depress the telescope plunge the telescope and again bring the intersection of the cross wires and bring the horizontal wire to the bottom of the vertical. If the intersection of the wires is again on the same side and at the same distance from the selected vertical the adjustment is correct. If it is not so raise or lower the movable support by the proper adjusting screws so as to correct half the difference and repeat the operation. If the instrument is erecting, raising the support will move the intersection away from it, or lowering the support will move the intersection toward it. If inverting, the reverse.

4th adjustment.—To make the vertical wire perpendicular to the horizontal axis.

Level carefully and lay the top of the wire on a definite point. Elevate the telescope slowly and note whether the point remains on the wire. If not, loosen two *adjacent* reticle screws and tap the head of one very gently until the point will travel on the wire from end to end. Then tighten the screws. If gently tapping on a screw head does not move the wire, tap on the opposite side of the opposite screw.

For a transit without vertical limb or attached level, known in the trade as a **plain transit**, the adjustments are now complete. If the transit has an attached level its axis is made parallel to the line of sight by the—

5th adjustment.—Set up midway between two stakes, which have their tops at about the same elevation, and with the bubble of the attached level in the center, read a rod on each stake. The difference in the readings is the true difference in level of the tops of the stakes. Move the instrument toward one of the stakes and set it up so that the eyepiece is about over the center of the stake. Place the rod on the stake near the eyepiece and set the target in the middle of the field as seen through the *object glass*. Set up the rod on the far stake with a target set at the reading just taken through the object glass, plus or minus the difference of level between stakes—plus if lower, minus if higher. Bisect the target with the horizontal cross wire. The line of sight must now be horizontal, and, keeping the vertical motion clamped so as to retain the pointing, adjust the bubble of the attached level to the center by means of the small screws at the movable end of its tube. Both line of sight and axis of bubble are now horizontal and therefore parallel

Note that the position of the horizontal wire in the field is a matter of convenience mainly. It is best to have it near the middle of the field, and it can be placed there by inspection with all needful precision.

6th adjustment.—If the transit has a vertical limb in addition to the attached level, the line of sight and axis of the attached level made parallel to each other by the preceding adjustment should also be so adjusted that the vertical scale will read zero when they are horizontal. If the vernier of the vertical limb is adjustable, bring the bubble of the attached level to the center and then adjust the vernier to read zero. If the vernier is fixed the reading, when the attached level is horizontal, may be taken as an index error and applied to all readings, or the line of sight may be adjusted to the vernier. To do this, establish a horizontal line from the center of the level to the target, as explained in the preceding adjustme[illegible] the vertical limb so that the vernier reads zero and bring th[illegible] of the wires onto the target by the top and bottom reticle screws. Then keeping the intersection on the target, bring the bubble of the attached level to the center by its adjusting screws. The line of sight and the axis of the attached level are now parallel and are horizontal when the vertical limb is at zero, which completes the adjustment.

102. **Use of the transit.**—To measure a horizontal angle, set up over the vertex of the angle to be measured, and direct the telescope along one of the sides of the angle. Clamp limb and plate—if the latter is set at zero it is more convenient—and with the tangent screw of the limb bring the intersection of the cross hairs on a definite point of the line. Read each of the two verniers and record, calling one vernier **A** and one **B.** Unclamp the plate—not the limb—and direct the telescope along the other line. Clamp and bring the cross hairs to a definite point with the vernier tangent screw. Read and record as before. Take the differences of the two readings **A** and **B,** respectively. If these differences are the same, it is the value of the angle. If not, take the mean of the differences as the value. **For greater accuracy,** the method of **repetition** is used. After the first measurement is made, unclamp the limb—not the plate—and re-sight on the first point by means of the limb tangent screw, and proceed as before. The reading of the vernier is now twice the angle. Continue the repetitions until the desired number are made. The last reading divided by the number of measurements is the value of the angle. To guard against errors, it is well to read and record after each measurement.

To measure a vertical angle.—Point the instrument; clamp the horizontal motions and make the readings on the vertical limb. For greater accuracy when there is a complete vertical circle, revolve the instrument through 180°, plunge the telescope, and take new readings. If the results differ, use the mean.

To run out a straight line.—Set up accurately over the initial point. Point the telescope in the required direction and establish a second point. These two determine the line which is to be run out. Set up over the forward or second point; lay the telescope on the initial point; clamp limb and plate; plunge telescope and set a point forward. If the adjustments are good, this third point will be in line with the first and second and the line may be prolonged by repeating the steps taken at the second point.

If the adjustments are not good, set a third point as before. Then unclamp the limb and turn 180° in azimuth and lay on the initial point. Clamp and plunge again and set another third point beside the first one. Take the middle point between the two for the true third point. This method eliminates errors of adjustment, except those of the plate levels. These are so easily observed and corrected that they should never exist when close work is required.

103. **Traversing.**—The transit must be set at each station with the 0–180° line of the azimuth circle parallel to its position at preceding stations. This is called **carrying an azimuth.** The direction chosen for the 0–180° line is usually the true N. and S., or as near it as data at hand will permit.

Having observed the second station from the first, proceed to the second, set up, and set one of the verniers at its reading from the first to the second station, plus 180°, or at the **back azimuth.** Point at the first station and clamp the limb. The line 0–180° is now in a position parallel to that at the first station. Unclamp the plate, direct the telescope to the third station, and proceed as before.

104. **Stadia surveying,** or **stadia work,** is in theory the determination of the distance of an object along the line of sight from the size of its image in a telescope. In usual practice it is the determination of the distance from the size of the object at that distance which is required to produce an image of a fixed size in the telescope. The sizes of objects required to produce an image of fixed size are directly proportional to their distances from the point over which the telescope is set. This hypothesis is not rigidly correct, but the theoretical error is small and the practical errors negligible.

The **limits** of the **image** in the telescope are fixed by two horizontal wires in the reticle, called **stadia wires,** one above and one below the middle wire, and at nearly equal distances from it. The **object** most convenient to use is a **graduated rod** held vertically. Special graduations are used, presenting a variety of forms, so that different units may be recognized as far as the rod can be seen, and so also that small readings may be taken by estimating the position of the wire on a diagonal line. Very many different forms of stadia graduations have been proposed, and most experienced stadia workers have special forms which they consider better than any other. Figure 80 shows a form which has received wide approval and may safely be accepted as one of the best.

Wires can not be placed in reticles exactly at predetermined distances, even though the places for them are accurately marked by the maker. They must be placed as accurately as possible, and their actual distances determined afterwards. Hence stadia rods are not in the market as level rods are, but must be made for each instrument. To minimize error of refraction, the upper wire should be placed on the primary division nearest the top of the rod and the graduations counted downward. Rods should be of light, straight-grained, well-seasoned wood, 12 to 14 feet long, 5 inches wide, and ⅞ inch thick, dressed smooth all around, and covered with two coats of white paint.

To graduate the rod, set the transit up over a point, and from the point measure off a distance in round hundreds of feet so that at that distance somewhat more than half of the rod falls between the stadia wires. Set the top wire near the top of the rod, and have the point where each wire cuts the rod carefully marked. Measure the distance between the extreme marks and divide it by the number of hundreds of feet in the distance of the rod from the transit point. The result is the length on the rod corresponding to 100 feet. Lay this distance off on the rod, beginning near the top and repeating to the bottom. Divide each 100-foot space according to the style chosen, and mark the graduations. All distances read on this rod, except the one at which the length of graduation was found, will be slightly in error; those less, too small; and those greater, too large.

A rod may be so graduated as to be practically free from error. Mark the zero near the top of the rod. Set the rod up at, say, 100 feet, bring the top wire to the zero, and mark the bottom one. Carry the rod to 200 feet and repeat the operation. Continue at intervals of 100 feet until the full length of the rod falls between the wires. Each of the marks corresponds to the distance at which it was made, and the space between it and the next, to the corresponding 100-foot interval. The 100-foot divisions are not exactly of equal length, and each must be divided into equal parts and marked. In using this rod, the top wire must be always at the top of the rod, and the same end of the rod always up, or error will be introduced. For long distances the reading from the top to the middle wire may be taken and multiplied by the ratio of the full to the partial interval. This ratio should be determined with care and may be utilized to secure a reading when all the rod can not be seen and which would otherwise be lost.

The stadia is used in connection with a transit with vertical limb, or a plane table. By reading a stadia rod through either instrument and noting the gradient and azimuth at the same time, a point may be completely determined both in position and elevation at a single observation. The distance measured is along the gradient, and may be reduced to the horizontal if desired, by Table XII. The elevation is obtained from Table III. Before reading the vertical circle, depress the telescope until the middle wire is on a rod graduation at the same distance from the bottom that the telescope is above the station or the ground.

*These ins*tructions will introduce some the rod is always *held vertical. It amounts to 1 per cen* tance for a gra-

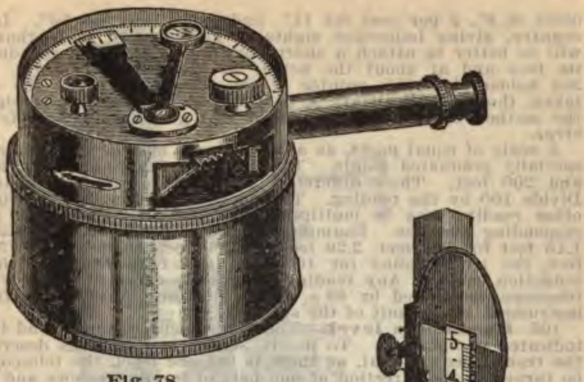


Fig. 78

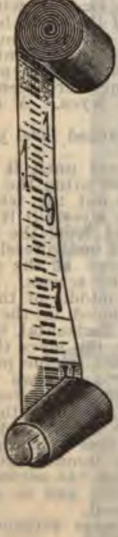


Fig. 79

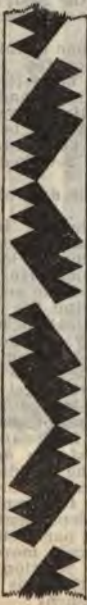


Fig. 80

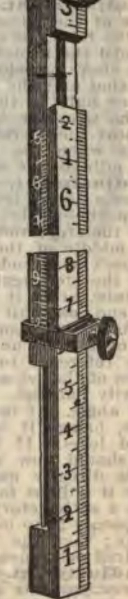


Fig. 81

dient of 8°, 2 per cent for 11°, and 3 per cent for 14°. In rough country, giving important sights at gradients of more than 5°, it will be better to attach a short pointer to the rod perpendicular to its face and at about the height of the rod-holder's eye. If the rod holder aims this pointer at the instrument when the sight is taken, the rod will always be perpendicular to the line of sight, and the method of reduction explained will give results free from this error.

A scale of equal parts, as a **level rod**, may be used instead of a specially graduated stadia. Take two careful readings at, say, 100 and 200 feet. Their difference is the true reading for 100 feet. Divide 100 by the reading. The quotient is a factor, by which any other reading may be multiplied, and the product will be the corresponding distance. Example: If the readings on a level rod are 1.15 feet for 100 feet, 2.29 feet for 200 feet, then $2.29-1.15=1.14$ feet, the true reading for 100 feet $100\div1.14=88+$, which is the reduction factor. Any reading on a scale of equal parts with this telescope, multiplied by 88 + is the distance of the scale from the instrument in the unit of the scale.

105. **Engineer's level.**—This instrument is shown and its parts indicated in figure 82. To use it, set up and focus as described for the transit, except that, as there is but one level, the telescope must be turned in the direction of one pair of leveling screws and leveled, and then turned in the direction of the other pair and leveled again. The second leveling may disturb the first, which should be retested.

1st adjustment.—To fix the intersection of the cross wires in the axis of the telescope:

Lay the telescope exactly on some definite point. Revolve it in the wyes until the attached level is on top. If the horizontal wire now appears above or below the point, move it over half the space between its position and the point by the top and bottom reticle screws and the other half by the main leveling screws of the instrument. Revolve the telescope in the wyes till it is again in the first position and repeat the operation till the horizontal wire neither ascends nor descends when the telescope is revolved in the wyes. A similar process adjusts the vertical wire.

2d adjustment.—To make the axis of the attached level parallel to the axis of the telescope:

Clamp the level; turn the telescope in the wyes until it comes against the stop, and with the main leveling screws bring the bubble to the middle of the tube. Open the loops, lift out the telescope, put it back with ends reversed, and turn it in the wyes till it comes against the stop again. If the bubble settles away from the middle of the tube, bring it back by raising the lower end or depressing the higher end, one-half by the vertical adjusting screw at the end of the attached level and one-half by the main leveling screws. Repeat all the operations until the bubble remains in the middle of the tube without reference to the way the telescope is placed in the wyes. The axes of the telescope and of the level are now horizontal, but not necessarily parallel. Turn the telescope slowly in the wyes through a small angle. If the bubble does not remain at the middle point of its tube, brings it back by the *horizontal* adjusting screws of the attached level. If both parts of the adjustment are perfect, the bubble should now remain at the middle of its tube whether the latter is directly under the telescope or a little to one side. In practice it will be found difficult to complete the first of the adjustment in a satisfactory manner independently of the second part. The best sequence is to make the first part roughly; then the second part carefully; then the first part again more carefully, and so on till the desired permanency of bubble position is attained.

3d adjustment.—To make the axis of the wyes perpendicular to the vertical axis of the instrument:

This adjustment is not essential, but it is a convenience, as it *permits the* telescope to be revolved about the vertical axis without *releveling before a reading* is made. Level the instrument in any

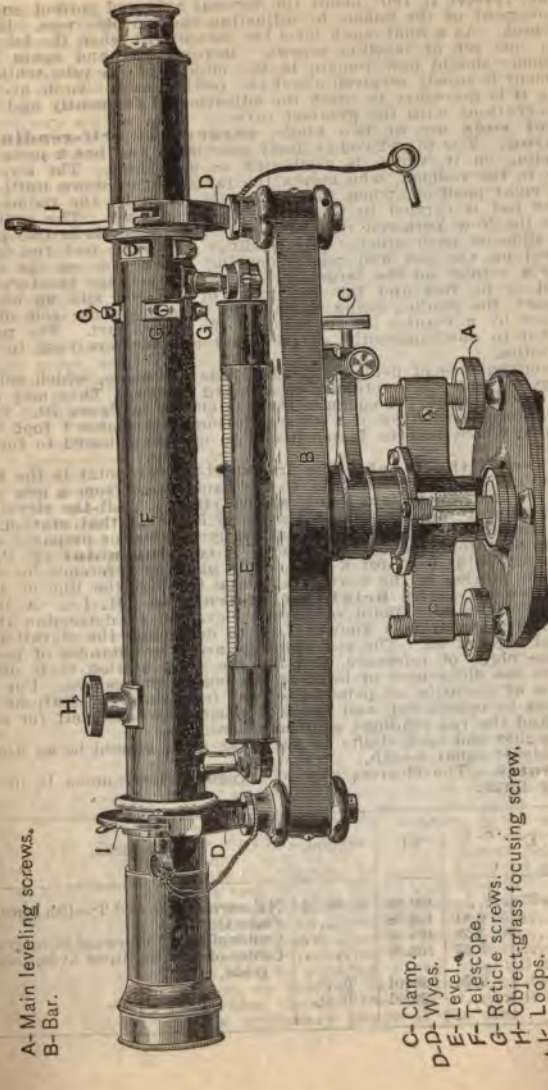


Fig. 82

A- Main leveling screws.
B- Bar.

C- Clamp.
D-D- Wyes.
E- Level.
F- Telescope.
G- Reticle screws.
H- Object-glass focusing screw.
I-I- Loops.

[illegible] about the vertical axis and correct one-half [illegible] by adjusting the movable wye. Repeat [illegible] level the instrument when the telescope [illegible] screws. Revolve 90° and again level. [illegible] in the middle of its tube while the [illegible] about the vertical axis. To do accurate [illegible] check the adjustments frequently and make [illegible] care.

[illegible] kinds, **target** and **self-reading** or [illegible] graduated and has a metal tar[illegible] graduated as a vernier. The levelman [illegible] moves the target up or down until it is [illegible] the reading is taken by the rodman, or [illegible] to the levelman to be read. The ordinary [illegible] 81). The rod proper is in two parts, [illegible] readings up to 6½ feet the target [illegible] read from the graduation on the front [illegible] on the target. For greater readings the target is [illegible] and the back part of the rod slid up on the [illegible] taken from a scale on the *side* of the [illegible] on the side of the front part. The rod is [illegible] of feet, and the verniers read to one-[illegible]

[illegible] field use flexible rods are made, which roll up [illegible] on a board for use. They may even [illegible] A common form is shown in figure 79. There [illegible] of a series of aluminum plates 1 foot long, [illegible] fastened end to end on a board to form a [illegible]

[illegible] The first sight to any point is the **fore** [illegible] sight to the same point from a new posi[illegible] is a **back sight** (B. S.). All the elevations [illegible] depend upon the B. S. at that station. A [illegible] is a point especially selected or prepared with [illegible] and permanency. A **turning point** (T. P.) is [illegible] for a B. S. The plane of reference for each [illegible] the horizontal plane through the line of sight [illegible] called **height of instrument** (H. I.). A B. S. [illegible] to a point of known elevation to determine H. I. [illegible] from a known H. I. to determine the elevation of [illegible]. The rod readings are the distances of points [illegible] of reference, and for the same station their differ[illegible] differences of level of the points themselves. For the [illegible] elevation of points observed from different stations the [illegible] considered, and hence it must be worked out for each [illegible] the rod readings subtracted from it.

[illegible] and back sights on the same point should be as nearly [illegible] equal length.

[illegible] **Notes.**—The clearest way of recording level notes is in the [illegible]

B. S.	H. I.	F. S.	El.	Station.	Remarks.
[illegible]	[illegible]	....	[illegible]	B. M. 21	NE. corner Main and Twelfth Streets.
[illegible]	[illegible]	[illegible]	102.34	....	Stake 132.
[illegible]	[illegible]	[illegible]	103.41	....	Center of Twelfth Street at top of grade.
[illegible]	[illegible]	[illegible]	103.38	....	Center of Twelfth Street at bottom of grade.
		9.74	99.01	T. P.	
[illegible]	[illegible]	....	99.01	T. P.	

Add the B. S. to the elevation of the B. M. or T. P. for the H. I. Subtract the F. S. from the H. I. for the elevation of a point. As a check, the H. I. at any B. M. or T. P. plus the F. S. to that point, minue the B. S. from that point, equals the last preceding H. I.

108. **The sextant.**—This instrument is shown and its parts indicated in figures 78 and 83. The former is a very compact form, called the **pocket sextant,** and is the one in most general use in the military service. The larger form (fig. 83) has telescopes of different powers and also a telescope tube without lenses which is used for reconnaissance work at short ranges. The pocket sextant has a telescope for use in astronomical and long-range terrestrial work. For ordinary reconnaissance and surveying the pocket sextant is used without the telescope, the sight being taken through a small hole in the slide which closes the telescope opening.

The adjustments are as follows: For the index glass, place the vernier at about 30° of the limb and examine the arc and its image in the index glass. If the arc and image appear continuous the glass is in adjustment. If the image appears above the arc the mirror leans forward; if below, it leans backward. Adjust with screws if provided, or with slips of paper inserted between the mirror and its frame.

For the horizon glass.—Set at zero and observe a well-defined distant point, using the telescope. If the direct and reflected images coincide, the horizon glass is in adjustment. If not, adjust it until they do, or if that can not be conveniently done, move the arm a short distance from zero until coincidence occurs. Read the vernier and apply that reading with its proper sign to all angles measured. Such a reading applied as a correction is called the **index error.** If the index error is **off the arc,** that is, between zero and the end, it is additive. If **on the arc,** subtractive.

In the pocket form the horizon glass only is adjustable. **To adjust the pocket sextant,** select a distant object with a clearly defined straight outline. Set the vernier carefully at the zero of the arc and look at the object through the peephole and the lower portion of the horizon glass. Turn the sextant about the line of sight as an axis until the straight line appears to be perpendicular to the straight bottom edge of the horizon glass. If the instrument is not perfectly adjusted for this position the straight line of the observed object will appear broken, in which case unscrew the smaller milled head of the top plate, and, using its small end as a key, turn the single adjusting screw in the cylindrical surface while looking at the object through the peep. The part of the image seen in the mirror will appear to move, and by turning the key in the proper direction the two parts may be brought together. Next turn the sextant about 60° about the line of sight, and if the straight line again appears broken use the key to slightly loosen one of the two adjusting screws in the top plate while looking through the instrument. If this brings the two parts nearer in line the proper screw has been selected; if not try the other one. Then turn the two adjusting screws in the top plate by corresponding amounts and in opposite directions and continue turning them alternately till the straight line becomes continuous. The two screws are opposed to each other, and care must be taken to use no considerable force and to always unscrew one before screwing up the other. When the adjustment is complete the line should remain continuous and straight while the sextant is slowly revolved about the line of sight. If the index arm is then moved back and forth by turning the large milled head the reflection of any object may be made to pass exactly over that object as seen through the clear glass.

For adjusting at night, screw the telescope in place. Pull its inner tube well out. Remove the sunglass from the eyepiece. Focus the telescope on a bright star by pushing in the tube till the image of the star is clear. Then, by turning the large milled head, make the star's reflected image pass through the field of view. If it does not pass exactly over the stationary image of the star, adjust the

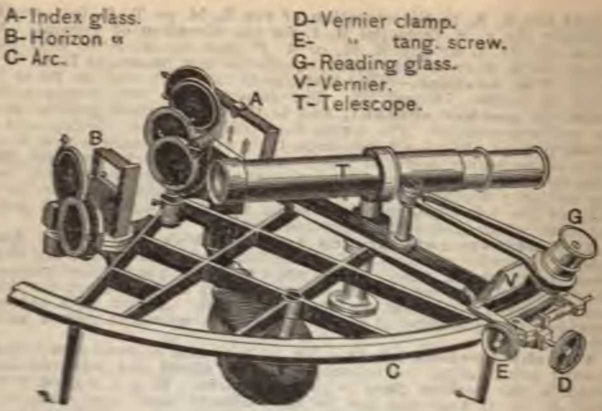

A- Index glass.
B- Horizon "
C- Arc.
D- Vernier clamp.
E- " tang. screw.
G- Reading glass.
V- Vernier.
T- Telescope.
A
B
T
G
V
C
E
D

Fig. 83

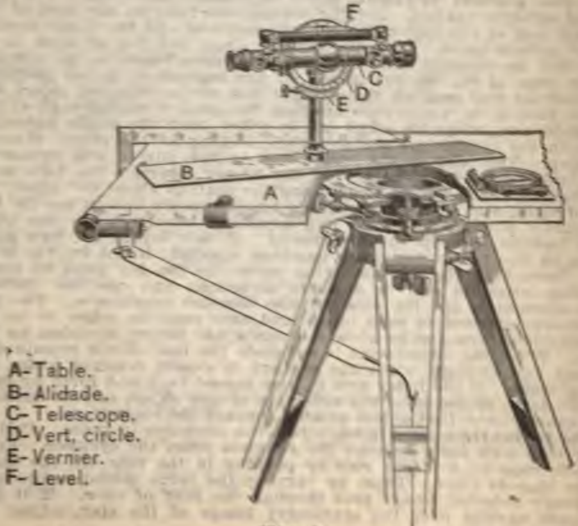

F
C
D
E
B
A
A- Table.
B- Alidade.
C- Telescope.
D- Vert. circle.
E- Vernier.
F- Level.

Fig. 84

horizon glass with the two screws in the top plate till one image will pass exactly over the other. Next set the vernier accurately to the zero of the arc, and with the single adjusting screw in the cylindrical surface make the two images appear as one. The instrument is then completely adjusted. The daylight method is most convenient, but it is well to test the adjustment by the star method before attempting to do any astronomical work.

In the cylindrical surface just below the zero degree end of the arc are two projecting levers which move colored glasses to be used in looking at the sun. At other times these glasses should be depressed through the opening in the bottom plate by first sliding the brass stud in the plate and then pushing the two levers. The telescope also has a colored sunglass secured on the eye end which must be removed when observing any other object.

109. **The plane table.**—The instrument is shown and its parts indicated in figure 84.

The adjustments are analogous to those of the transit, the table corresponding to the limb and the ruler to the plate. In revolving the plate for level adjustment, care must be taken to have it cover the same part of the table in both positions by marking two corners on the paper. The figure shows a device for plumbing any point on the table over a given point on the ground. Except for very close work on a very large scale, this refinement is unnecessary. For all probable uses in the military service it is enough to place the corresponding part of the drawing over the station by the eye.

110. **The logarithm of a number** is the exponent of the power to which a certain other number, called the base, must be raised to produce the given number. The base of the system most used, called **common logarithms,** is 10.

In any system—

The log. of a product equals the sum of the logs. of the factors.

The logs. of a quotient equals the log. of the dividend minus the log. of the divisor; or the log. of a common fraction equals the log. of the numerator minus the log. of the denominator.

The log. of 1 is 0; since the log. 1=the log. =the log. 1−log. 1=0. The log. of a power of a number equals the log. of the number multiplied by the exponent of the power. The log. of a root of a number equals the log. of the number divided by the index of the root.

The first property above is utilized in the construction of the tables. Each log. is the sum of the logs. of two factors of which its number is composed, and the factors may be so chosen that the log. of one is a whole number, called the **characteristic,** and the log. of the other is a decimal fraction, called the **mantissa.** Any number may be resolved into two factors one of which is the number itself with the decimal point after the first significant figure and the other the figure 1, alone, or followed or preceded by one or more ciphers.

Thus:	$3760=3.76\times1000$	log.$=3.57518$
	$376=3.76\times100$	log.$=2.57518$
	$37.6=3.76\times10$	log.$=1.57518$
	$3.76=3.76\times1$	log.$=0.57518$
	$0.376=3.76\times0.1$	log.$=\bar{1}.57518$
	$0.0376=3.76\times0.01$	log.$=\bar{2}.57518$
	$0.00376=3.76\times0.001$	log.$=\bar{3}.57518$

The log. of the constant factor, 3.76 in the above example, is always a positive decimal fraction, and is called the **mantissa.** The log. of the variable factor in the third column above, is a whole number, and may be positive or negative. It is called the **characteristic.** The logs. of all numbers presenting the same combination of significant figures have the same mantissa regardless of the position of the decimal point. **Logarithmic tables contain mantissas only,** since the characteristics may be written by inspection and mental calculation. To this rule tables of logarithmic circular functions are an exception, as will be explained later. If the number is **whole or mixed,** the characteristic of its log. is positive, and **one less** than the number of places of figures in the integral part, or on the **left of the decimal point.** If the number is a decimal fraction, the characteristic of its log. is **negative,** and **one greater** than the number of ciphers **immediately following the decimal point.** See example preceding. **If the characteristic is positive,** the log. is a mixed number, and may be treated as such in addition, subtraction, multiplication, and division.

If the characteristic is negative, the log. is not a true mixed number, and special treatment is necessary. A negative characteristic may be considered as composed of two numbers, one negative and the other positive. The positive number, prefixed to the mantissa, forms a mixed number for arithmetical operations. The positive and negative parts may be simultaneously increased numerically by the same number without altering the value of the log.

Thus:

$$\begin{aligned}\bar{3}.4281 &= \bar{3} + 0.4281\\ &= \bar{4} + 1.4281\\ &= \bar{5} + 2.4281, \text{ etc.}\end{aligned}$$

For example, to multiply $\bar{4}.7265$ by 4.

$$\begin{array}{r}\bar{4} + 0.7265\\ 4\\ \hline \overline{16} + 2.9060 = \overline{14}.9060,\end{array}$$ which is the required result.

To subtract $\bar{1}.8432$ from $\bar{3}.1329 = \bar{4} + 1.1329$.

$$\begin{array}{l}\bar{4} + 1.1329\\ \underline{\bar{1} + 0.8432}\\ \bar{3} + 0.2897 = 3.2897.\end{array}$$

To divide $\bar{2}.2368$ by 7. $\bar{2}.2368 = \bar{7} + 5.2368$.

$$\frac{\bar{7} + 5.2368}{7} = \bar{1} + 0.7481 = \bar{1}.7481$$

In this case the number added to the minus characteristic should be just enough to make it *exactly divisible* by the divisor.

In the logs. of circular functions a characteristic is given in the tables which is larger by 10 than the true characteristic. These logs. may be used by the above rule by prefixing $\overline{10}$ to each. Thus the log. sine of 21 min. as given in the table=7.78594. The true log. is $\overline{10}$ + 7.78594, or 3.78594. Those who are familiar with the use of these logs. perform the operation on the $\overline{10}$ mentally. The inexperienced will do well to write them out in full.

111. Explanation of the table.—Table XIII gives to five decimal places the common logs. of numbers from 0 to 999 directly and by interpolation from 0 to 9999. If the log. of a number larger than 10000 is desired, factor it and take the sum of the logs. of the factors. Thus log. 99225=log. of 75000 plus the log. of 1.323= 4.87506 + 0.12156=4.99662. Or convert the number into a mixed number less than 1000 and find its log. Thus log. 992.25=992 + $\frac{1}{4}$ diff. between 992 and 993=99662, which is the mantissa for 99225.

In the table the logs. of 2 to 9 inclusive are found at the tops of the columns. For numbers above 10, the first two figures are in the first column, the third at the tops of the columns, and the fourth is interpolated. The right-hand column contains the average difference in each line between logs. in successive columns. For the fourth place multiply $\frac{1}{10}$ of the difference on the same line by the fourth figure and add the product to the log. of the first three figures. Thus:

To find the log. of 4827, look for 48 in the left-hand column; follow the line to the column headed 2 and take out the mantissa .68304 for the number 482. In the right-hand column on the same line is the difference 90, $\frac{1}{10}$ of which, 9, multiplied by the fourth figure 7, =

63, to be added to the log. of 482, making the mantissa of 4827= .68367. The characteristic is 3 or 1 less than the number of places of integral figures in the number. Hence the complete log. of 4827 is 3.68367.

When the difference exceeds 200, if close results are desired, use the difference obtained by subtracting the number found for the third figure from that in the column for the next higher figure.

The number corresponding to any log. may be obtained from the table by the inverse process. If the given log. is found in the table, the corresponding number consists of the two figures on the left of the line, followed by the one at the top of the column. If the exact log. is not in the table, find the next one below and take out the three figures for that. Take the difference between the given log. and the one found in the table next below it and divide this diff. by $\frac{1}{10}$ the tabulated diff. on the line. Write down the quotient for the fourth figure of the required number.

Thus to find the number corresponding to 1.49638. This is not in the table and the next below is 49554. The two figures on the left of the line are 31 and the figure at top of column is 3. Hence 313 is the number corresponding to 49554. The difference between 49638 and 49554 is 74, which, divided by 14 or $\frac{1}{10}$ of the tabulated diff. 138 on the right of the line, gives a quotient of 5+ to be set down as the fourth figure. Hence the number required is 0.3135, since the characteristic is 1, and therefore the significant figures are immediately after the decimal point.

Table XIII.

112. **Common logarithms,** 1 to 999:

No.	0	1	2	3	4	5	6	7	8	9	Diff.
	....	00000	30130	47712	60206	69897	77815	84510	90309	95424	....
10	00000	00432	00860	01283	01703	02118	02530	02938	03342	03742	415
11	04139	04532	04921	05307	05690	06069	06445	06818	07188	07554	379
12	07918	08278	08636	08990	09342	09691	10037	10380	10721	11059	349
13	11394	11727	12057	12385	12710	13033	13353	13672	13987	14301	323
14	14613	14921	15228	15533	15836	16136	16435	16731	17026	17318	300
15	17609	17897	18184	18469	18752	19033	19312	19590	19865	20139	281
16	20412	20682	20951	21218	21484	21748	22010	22271	22530	22788	264
17	23045	23299	23552	23804	24054	24303	24551	24797	25042	25285	249
18	25527	25767	26007	26245	26481	26717	26951	27184	27415	27646	236
19	27875	28103	28330	28555	28780	29003	29225	29446	29666	29885	223
20	30103	30319	30535	30749	30963	31175	31386	31597	31806	32014	212
21	32222	32428	32633	32838	33041	33243	33445	33646	33845	34044	202
22	34242	34439	34635	34830	35024	35218	35410	35602	35793	35983	194
23	36173	36361	36548	36735	36921	37106	37291	37474	37657	37839	185
24	38021	38201	38381	38560	38739	38916	39093	39269	39445	39619	177
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330	171
26	41497	41664	41830	41995	42160	42324	42488	42651	42813	42975	164
27	43136	43296	43456	43616	43775	43933	44090	44248	44404	44560	158
28	44716	44870	45024	45178	45331	45484	45636	45788	45939	46089	153
29	46240	46389	46538	46686	46834	46982	47129	47275	47421	47567	148
30	47712	47856	48000	48144	48287	48430	48572	48713	48855	48995	143
31	49136	49276	49415	49554	49693	49831	49968	50105	50242	50379	138
32	50515	50650	50785	50920	51054	51188	51321	51454	51587	51719	134
33	51851	51982	52113	52244	52374	52504	52633	52763	52891	53020	130
34	53148	53275	53402	53529	53655	53781	53907	54033	54157	54282	126
35	54407	54530	54654	54777	54900	55022	55145	55266	55388	55509	122
36	55630	55750	55870	55990	56110	56229	56348	56466	56584	56702	119
37	56820	56937	57054	57170	57287	57403	57518	57634	57749	57863	116
38	57978	58092	58206	58319	58433	58546	58658	58771	58883	58995	113
39	59106	59217	59328	59439	59549	59659	59769	59879	59988	60097	110
40	60206	60314	60422	60530	60638	60745	60852	60959	61066	61172	107
41	61278	61384	61489	61595	61700	61804	61909	62013	62118	62221	104
42	62325	62428	62531	62634	62736	62838	62941	63042	63144	63245	102
43	63347	63447	63548	63648	63749	63848	63948	64048	64147	64246	99
44	64345	64443	64542	64640	64738	64836	64933	65030	65127	65224	98
45	65321	65417	65513	65609	65705	65801	65896	65991	66086	66181	96
46	66276	66370	66464	66558	66651	66745	66838	60931	67024	67117	94
47	67210	67302	67394	67486	67577	67669	67760	67851	67942	68033	92
48	68124	68214	68304	68394	68484	68574	68663	68752	68842	68930	90
49	69020	69108	69196	69284	69372	69460	69548	69635	69722	69810	88
50	69897	69983	70070	70156	70243	70329	70415	70500	70586	70671	86
51	70757	70842	70927	71011	71096	71180	71265	71349	71433	71516	84
52	71600	71683	71767	71850	71933	72015	72098	72181	72263	72345	82
53	72428	72509	72591	72672	72754	72835	72916	72997	73078	73158	81
54	73239	73319	73399	73480	73559	73639	73719	73798	73878	73957	80
55	74036	74115	74193	74272	74351	74429	74507	74585	74663	74741	78
56	74818	74896	74973	75050	75127	75204	75281	75358	75434	75511	77
57	75587	75663	75739	75815	75891	75966	76042	76117	76192	76267	75
58	76342	76417	76492	76566	76641	76715	76789	76863	76937	77011	74
59	77085	77158	77232	77305	77378	77451	77524	77597	77670	77742	73
	77815	77887	77959	78031	78103	78175	78247	78318	78390	78461	72

TABLE XIII.—**Common logarithms**—Continued.

No.	0	1	2	3	4	5	6	7	8	9	Diff.
61	78533	78604	78675	78746	78816	78887	78958	79028	79098	79169	71
62	79239	79309	79379	79448	79518	79588	79557	79726	79796	79865	70
63	79934	80002	80071	80140	80208	80277	80345	80413	80482	80550	69
64	80618	80685	80753	80821	80888	80956	81023	81090	81157	81224	68
65	81291	81358	81424	81491	81557	81624	81690	81756	81822	81888	67
66	81954	82020	82085	82151	82216	82282	82347	82412	82477	82542	66
67	82607	82672	82736	82801	82866	82930	82994	83058	83123	83187	65
68	83250	83314	83378	83442	83505	83569	83632	83695	83758	83821	64
69	83884	83947	84010	84073	84136	84198	84260	84323	84385	84447	63
70	84509	84571	84633	84695	84757	84818	84880	84941	85003	85064	62
71	85125	85187	85248	85309	85369	85430	85491	85551	85612	85672	61
72	85733	85753	85853	85913	85973	86033	86093	86153	86213	86272	60
73	86332	86391	86451	86510	86569	86628	86687	86746	86805	86864	59
74	86923	86981	87040	87098	87157	87215	87273	87332	87390	87448	58
75	87506	87564	87621	87679	87737	87794	87852	87909	87966	88024	57
76	88081	88138	88195	88252	88309	88366	88422	88479	88536	88592	56
77	88649	88705	88761	88818	88874	88930	88986	89042	89098	89153	56
78	89209	89265	89320	89376	89431	89487	89542	89597	89652	89707	55
79	89762	89817	89872	89927	89982	90036	90091	90145	90200	90254	54
80	90309	90363	90417	90471	90525	90579	90633	90687	90741	90794	54
81	90848	90902	90955	91009	91062	91115	91169	91222	91275	91328	53
82	91381	91434	91487	91540	91592	91645	91698	91750	91803	91855	53
83	91907	91960	92012	92064	92116	92168	92220	92272	92372	92376	52
84	92427	92479	92531	93582	92634	92685	92737	92788	92839	92890	51
85	92941	92993	93044	93095	93146	93196	93247	93298	93348	93399	51
86	93449	93500	93550	93601	93651	93701	93751	93802	93852	93902	50
87	93951	94001	94051	94101	94151	94200	94250	94300	94349	94398	49
88	94448	94497	94546	94596	94645	94694	94743	94792	94841	94890	49
89	94939	94987	95036	95085	95133	95182	95230	95279	95327	95376	48
90	95424	95472	95520	95568	95616	95664	95712	95760	95808	95856	48
91	95904	95951	95999	96047	96094	96142	96189	96236	96284	96331	48
92	96378	96426	96473	96520	96567	96614	96661	96708	96754	96801	47
93	96848	96895	96941	96988	97034	97081	97127	97174	97220	97266	47
94	97312	97359	97405	97451	97497	97543	97589	97635	97680	97726	46
95	97772	97818	97863	97909	97954	98000	98045	98091	98136	98181	46
96	98227	98272	98317	98362	98407	98452	98497	98542	98587	98632	45
97	98677	98721	98766	98811	98855	98900	98945	98989	99033	99078	45
98	99122	99166	99211	99255	99299	99343	99387	99431	99475	99519	44
99	99563	99607	99651	99694	99738	90782	99825	99869	99913	99956	44

113. TABLE XIV—Common logarithms of circular functions:

Arc. °	'	Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.	°	'
0	00	Inf. neg.	....	10.00000	....	Inf. neg.	....	Inf. pos.	90	00
	01	6.46373	....	10.00000	....	6.46373	....	13.53627		59
	02	.76476	30103	10.00000	....	.76476	30103	.23524		58
	03	6.94085	17609	10.00000	....	6.94085	17609	13.05915		57
	04	7.06579	12494	10.00000	....	7.06579	12494	12.93421		56
	05	.16270	9691	10.00000	....	.16270	9691	.83730		55
	06	.24188	7918	9.99999	....	.24188	7918	.75812		54
	07	.30882	6694	.99999	....	.30882	6694	.69117		53
	08	.36682	5800	.99999	....	.36682	5800	.63318		52
	09	.41797	5115	.99999	....	.41797	5115	.58203		51
	10	.46373	4576	.99999	....	.46373	4576	.53627		50
	11	7.50512	4139	9.99999	....	7.50512	4139	12.49488		49
	12	.54291	3779	.99999	....	.54291	3779	.45709		48
	13	.57767	3476	.99999	....	.57767	3476	.42233		47
	14	.60985	3218	.99999	....	.60986	3219	.39014		46
	15	.63982	2996	.99999	....	.63982	2996	.36108		45
	16	.66784	2803	.99999	....	.66785	2803	.33215		44
	17	.69417	2633	.99999	....	.69418	2633	.30582		43
	18	.71900	2482	.99999	....	.71900	2482	.28100		42
	19	.74248	2348	.99999	....	.74248	2348	.25752		41
	20	.76475	2227	.99999	....	.76476	2228	.23524		40
	21	7.78594	2119	9.99999	....	7.78595	2119	12.21405		39
	22	.80615	2020	.99999	....	.80615	2020	.19384		38
	23	.82545	1930	.99999	....	.82546	1931	.17454		37
	24	.84393	1848	.99999	....	.84394	1848	.15606		36
	25	.86166	1773	.99999	....	.86167	1773	.13833		35
	26	.87869	1703	.99999	....	.87871	1704	.12129		34
	27	.89508	1639	.99999	....	.89510	1639	.10490		33
	28	.91088	1580	.99999	....	.91089	1579	.08911		32
	29	.92612	1524	.99998	....	.92613	1524	.07387		31
	30	.94084	1472	.99998	....	.94086	1473	.05914		30
	31	7.95508	1424	9.99998	....	7.95510	1424	12.04490		29
	32	.96887	1379	.99998	....	.96889	1379	.03111		28
	33	.98223	1336	.99998	....	.98225	1336	.01775		27
	34	7.99520	1297	.99998	....	7.99522	1297	12.00478		26
	35	8.00779	1259	.99998	....	8.00781	1259	11.99219		25
	36	.02002	1223	.99998	....	.02004	1223	.97996		24
	37	.03192	1190	.99997	....	.03194	1190	.96805		23
	38	.04350	1158	.99997	....	.04353	1158	.95647		22
	39	.05478	1128	.99997	....	.05481	1128	.94519		21
	40	.06578	1100	.99997	....	.06581	1100	.93419		20
0	41	8.07650	1072	9.99997	....	8.07653	1072	11.92347		19
	42	.08696	1046	.99997	....	.08700	1047	.91300		18
	43	.09718	1022	.99997	....	.09722	1022	.90278		17
	44	.10717	998	.99996	....	.10720	999	.89280		16
	45	.11693	976	.99996	....	.11696	976	.88304		15
	46	.12647	954	.99996	....	.12651	955	.87349		14
	47	.13581	934	.99996	....	.13585	934	.86415		13
	48	.14495	914	.99996	....	.14500	915	.85500		12
	49	.15391	895	.99996	....	.15395	895	.84605		11
	50	.16268	877	.99995	....	.16273	878	.83727		10
	51	8.17128	860	9.99995	....	8.17133	860	11.82867		9
	52	.17971	843	.99995	....	.17976	843	.82024		8
	53	.18798	827	.99995	....	.18804	828	.81196		7
	54	.19610	812	.99995	....	.19616	812	.80384		6
	55	.20407	797	.99994	....	.20413	797	.79587		5
	56	.21189	782	.99994	....	.21195	782	.78805		4
		21958	769	.99994	....	.21964	769	.78036		3
		22713	755	.99994	....	.22719	755	.77280		2
		3456	743	.99994	....	.23462	743	.76538		1
		4185	729	9.99993	....	8.24192	730	11.75808	89	0
		ne.	Diff.	Sine	Diff.	Cotang	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—Contd.

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
1	00	8.24185	729	9.99993	....	8.24192	730	11.75808		60
	01	.24903	718	.99993	....	.24910	718	.75090		59
	02	.25609	706	.99993	....	.25616	706	.74383		58
	03	.26304	695	.99993	....	.26311	695	.73688		57
	04	.26988	684	.99992	....	.26996	685	.73004		56
	05	.27661	673	.99992	....	.27669	673	.72331		55
	06	.28324	663	.99992	....	.28332	663	.71668		54
	07	.28977	653	.99992	....	.28986	654	.71014		53
	08	.29621	644	.99991	....	.29629	643	.70371		52
	09	.30255	634	.99991	....	.30263	634	.69737		51
	10	.30879	624	.99991	....	.30888	625	.69112		50
	11	8.31495	616	9.99991	....	8.31505	617	11.68495		49
	12	.32103	608	.99990	....	.32112	607	.67888		48
	13	.32702	599	.99990	....	.32711	599	.67289		47
	14	.33292	590	.99990	....	.33302	591	.66697		46
	15	.33875	583	.99990	....	.33886	584	.66114		45
	16	.34450	575	.99989	....	.34461	575	.65539		44
	17	.35018	568	.99989	....	.35029	568	.64971		43
	18	.35578	560	.99989	....	.35589	560	.64410		42
	19	.36131	553	.99988	....	.36143	554	.63857		41
	20	.36678	547	.99988	....	.36689	546	.63310		40
1	21	8.37217	539	9.99988	....	8.37229	540	11.62771		39
	22	.37750	533	.99988	....	.37762	533	.62238		38
	23	.38276	526	.99987	....	.38289	527	.61711		37
	24	.38796	520	.99987	....	.38809	520	.61191		36
	25	.39310	514	.99987	....	.39323	514	.60677		35
	26	.39818	508	.99986	....	.39831	508	.60168		34
	27	.40320	502	.99986	....	.40334	503	.59666		33
	28	.40816	496	.99986	....	.40830	496	.59170		32
	29	.41307	491	.99985	....	.41321	491	.58679		31
	30	.41792	485	.99985	....	.41807	486	.58193		30
	31	8.42272	480	9.99985	....	8.42287	480	11.57713		29
	32	.42746	474	.99984	....	.42762	475	.57238		28
	33	.43216	470	.99984	....	.43231	469	.56768		27
	34	.43680	464	.99984	....	.43696	465	.56304		26
	35	.44139	459	.99983	....	.44156	460	.55844		25
	36	.44594	455	.99983	....	.44611	455	.55389		24
	37	.45044	450	.99983	....	.45061	450	.54939		23
	38	.45489	445	.99982	....	.45507	446	.54493		22
	39	.45930	441	.99982	....	.45948	441	.54052		21
	40	.46366	436	.99982	....	.46385	437	.53615		20
	41	8.46798	432	9.99981	....	8.46817	432	11.53183		19
	42	.47226	428	.99981	....	.47245	428	.52755		18
	43	.47650	424	.99980	....	.47669	424	.52331		17
	44	.48069	419	.99980	....	.48089	420	.51911		16
	45	.48485	416	.99980	....	.48505	416	.51495		15
	46	.48896	411	.99979	....	.48917	412	.51083		14
	47	.49304	408	.99979	....	.49325	408	.50675		13
	48	.49708	404	.99979	....	.49729	404	.50271		12
	49	.50108	400	.99978	....	.50130	401	.49870		11
	50	.50504	396	.99978	....	.50527	397	.49473		10
	51	8.50897	393	9.99977	....	8.50920	393	11.49080		9
	52	.51287	390	.99977	....	.51310	390	.48690		8
	53	.51673	386	.99976	....	.51696	386	.48304		7
	54	.52055	382	.99976	....	.52079	383	.47921		6
	55	.52434	379	.99976	....	.52459	380	.47541		5
	56	.52810	376	.99975	....	.52835	376	.47165		4
	57	.53183	373	.99975	....	.53208	373	.46792		3
	58	.53552	369	.99974	....	.53578	370	.46422		2
	59	.53919	367	.99874	....	.53945	367	.46055		
	60	*8.54282*	363	9.99973	....	8.54308	363	11.45692		
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang		

TABLE XIV—**Common logarithms of circular functions**—Contd.

Arc.	Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.	
° ′								° ′
2 00	8.54282	363	9.99973	....	8.54308	363	11.45692	60
01	.54642	360	.99973	....	.54669	361	.45331	59
02	.54999	357	.99973	....	.55027	358	.44973	58
03	.55354	355	.99972	....	.55382	355	.44618	57
04	.55705	351	.99972	....	.55734	352	.44266	56
05	.56054	349	.99971	....	.56083	349	.43917	55
06	.56400	346	.99971	....	.56429	346	.43571	54
07	.56743	343	.99970	....	.56773	344	.43227	53
08	.57084	341	.99970	....	.57114	341	.42886	52
09	.57421	337	.99969	....	.57452	338	.42548	51
10	.57757	336	.99969	....	.57788	336	.42212	50
11	8.58089	332	9.99968	....	8.58121	333	11.41879	49
12	.58419	330	.99968	....	.58451	330	.41549	48
13	.58747	328	.99967	....	.58779	328	.41220	47
14	.59072	325	.99967	....	.59105	326	.40895	46
15	.59395	323	.99966	....	.59428	323	.40572	45
16	.59715	320	.99966	....	.59749	321	.40251	44
17	.60033	318	.99965	....	.60068	319	.39932	43
18	.60349	316	.99965	....	.60384	316	.39316	42
19	.60662	313	.99964	....	.60698	314	.39302	41
20	.60973	311	.99964	....	.61009	311	.38991	40
21	8.61282	309	9.99963	....	8.61319	310	11.38681	39
22	.61589	307	.99963	....	.61626	307	.38374	38
23	.61894	305	.99962	....	.61931	305	.38069	37
24	.62196	302	.99962	....	.62234	303	.37766	36
25	.62496	300	.99961	....	.62535	301	.37465	35
26	.62795	299	.99961	....	.62834	299	.37166	34
27	.63091	296	.99960	....	.63131	297	.36869	33
28	.63385	294	.99960	....	.63426	295	.36574	32
29	.63678	293	.99959	....	.63718	292	.36282	31
30	.63968	290	.99959	....	.64009	291	.35991	30
31	8.64256	288	9.99958	....	8.64298	289	11.35702	29
32	.64543	287	.99957	....	.64585	287	.35415	28
33	.64827	284	.99957	....	.64870	285	.35130	27
34	.65110	283	.99956	....	.65154	284	.34846	26
35	.65391	281	.99956	....	.65435	281	.34565	25
36	.65670	279	.99955	....	.65715	280	.34285	24
37	.65947	277	.99955	....	.65993	278	.34007	23
38	.66223	276	.99954	....	.66269	276	.33731	22
39	.66497	274	.99953	....	.66543	274	.33457	21
40	.66769	272	.99953	....	.66816	273	.33184	20
2 41	8.67039	270	9.99952	....	8.67087	271	11.32913	19
42	.67308	269	.99952	....	.67356	269	.32644	18
43	.67575	267	.99951	....	.67624	268	.32376	17
44	.67840	265	.99951	....	.67890	266	.32110	16
45	.68104	264	.99950	....	.68154	264	.31846	15
46	.68366	262	.99949	....	.68417	263	.31583	14
47	.68627	261	.99949	....	.68678	261	.31322	13
48	.68886	259	.99948	....	.68938	260	.31062	12
49	.69144	258	.99947	....	.69196	258	.30804	11
50	.69400	256	.99947	....	.69453	257	.30547	10
51	8.69654	254	9.99946	....	8.69708	255	11.30292	9
52	.69907	253	.99946	....	.69962	254	.30038	8
53	.70159	252	.99945	....	.70214	252	.29786	7
54	.70409	250	.99944	....	.70465	251	.29535	6
55	.70658	249	.99944	....	.70714	249	.29286	5
56	.70905	247	.99943	....	.70962	248	.29038	4
57	.71151	246	.99942	....	.71208	246	.28792	3
58	.71395	244	.99942	....	.71453	245	.28547	2
59	.71638	243	.99941	....	.71697	244	.28303	1
	8.71880	*242*	9.99940	....	8.71940	243	11.28060	87 0
	Cosine.	*Diff.*	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.

TABLE XIV—**Common logarithms of circular functions**—Contd.

Arc.	Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.	
° '								° '
3 00	8.71880	242	9.99940	....	8.71940	243	11.28060	60
01	.72120	240	.99940	....	.72181	241	.27819	59
02	.72359	239	.99939	....	.72420	239	.27579	58
03	.72597	238	.99938	....	.72659	239	.27341	57
04	.72834	237	.99938	....	.62896	237	.27104	56
05	.73069	235	.99937	....	.73132	236	.26869	55
06	.73303	234	.99936	....	.73366	234	.26634	54
07	.73535	232	.99936	....	.73600	234	.26400	53
08	.73767	232	.99935	....	.73832	232	.26168	52
09	.73997	230	.99934	....	.74063	231	.25937	51
10	.74226	229	.99934	....	.74292	229	.25708	50
11	8.74454	228	9.99933	....	8.74521	229	11.25479	49
12	.74680	226	.99932	....	.74748	227	.25252	48
13	.74905	225	.99931	....	.74974	226	.25026	47
14	.75130	225	.99931	....	.75199	225	.24801	46
15	.75353	223	.99930	....	.75423	224	.24577	45
16	.75575	222	.99929	....	.75645	222	.24355	44
17	.75795	220	.99929	....	.75867	222	.24133	43
18	.76015	220	.99928	....	.76087	220	.23913	42
19	.76234	219	.99927	....	.76306	219	.23693	41
20	.76451	217	.99926	....	.76525	219	.23475	40
3 21	8.76667	216	9.99926	....	8.76742	217	11.23258	39
22	.76883	216	.99926	....	.76958	216	.23042	38
23	.77097	214	.99924	....	.77173	215	.22827	37
24	.77310	213	.99923	....	.77387	214	.22613	36
25	.77522	212	.99923	....	.77599	212	.22400	35
26	.77733	211	.99922	....	.77811	212	.22189	34
27	.77943	210	.99921	....	.78022	211	.21978	33
28	.78152	209	.99920	....	.78232	210	.21768	32
29	.78360	208	.99920	....	.78441	209	.21559	31
30	.78567	207	.99919	....	.78649	208	.21351	30
31	8.78774	207	9.99918	....	8.78855	206	11.21145	29
32	.78979	205	.99917	....	.79061	206	.20939	28
33	.79183	204	.99917	....	.79266	205	.20734	27
34	.79386	203	.99916	....	.79470	204	.20530	26
35	.79588	202	.99915	....	.79673	203	.20327	25
36	.79789	201	.99914	....	.79875	202	.20125	24
37	.79990	201	.99913	....	.80076	201	.19924	23
38	.80189	199	.99913	....	.80276	200	.19723	22
39	.80388	199	.99912	....	.80476	200	.19524	21
40	.80585	197	.99911	....	.80674	198	.19326	20
41	8.80782	197	9.99910	....	8.80872	198	11.19128	19
42	.80978	196	.99909	....	.81068	196	.18932	18
43	.81173	195	.99909	....	.81264	196	.18736	17
44	.81367	194	.99908	....	.81459	195	.18541	16
45	.81560	193	.99907	....	.81653	194	.18347	15
46	.81752	192	.99906	....	.81846	193	.18154	14
47	.81944	192	.99905	....	.82038	192	.17962	13
48	.82134	190	.99904	....	.82230	192	.17770	12
49	.82324	190	.99904	....	.82420	190	.17579	11
50	.82513	189	.99903	....	.82610	190	.17390	10
51	8.82701	188	9.99902	....	8.82799	189	11.17201	9
52	.82888	187	.99901	....	.82987	188	.17013	8
53	.83075	187	.99900	....	.83175	188	.16825	7
54	.83261	186	.99899	....	.83361	186	.16639	6
55	.83446	185	.99898	....	.83547	186	.16453	5
56	.83630	184	.99898	....	.83732	185	.16268	4
57	.83813	183	.99897	....	.83916	184	.16084	3
58	.83996	183	.99896	....	.84100	184	.15900	2
59	.84177	181	.99895	....	.84282	182	.15717	
60	*8.84358*	*181*	9.99894	....	8.84464	182	11.15536	
'	*Cosine.*	*Diff.*	Sine.	Diff	Cotang	Diff.	Tang.	

TABLE XIV—**Common logarithms of circular functions**—Contd.

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
4	00	8.84358	181	9.99894	1	8.84464	182	11.15536	86	00
	10	.86128	1770	.99885	9	.86243	1779	.13757		50
	20	.87828	1700	.99876	9	.87953	1710	.12047		40
	30	.89464	1636	.99866	10	.89598	1645	.10402		30
	40	.91040	1576	.99856	10	.91185	1587	.08815		20
	50	.92561	1521	.99845	11	.92716	1531	.07284		10
5	00	8.94030	1469	9.99834	11	8.94195	1479	11.05805	85	00
	10	.95450	1420	.99823	11	.95627	1432	.04373		50
	20	.96825	1375	.99812	11	.97013	1386	.02987		40
	30	.98157	1332	.99800	12	.98358	1345	.01642		30
	40	.99450	1293	.99787	13	.99662	1304	.00338		20
	50	9.00704	1254	.99774	13	9.00930	1268	10.99070		10
6	00	9.01923	1219	9.99761	13	9.02162	1232	10.97838	84	00
	10	.03109	1186	.99748	13	.03361	1199	.96639		50
	20	.04262	1153	.99734	14	.04528	1167	.95472		40
	30	.05386	1124	.99720	14	.05666	1138	.94334		30
	40	.06481	1095	.99705	15	.06775	1109	.93225		20
	50	.07548	1067	.99690	15	.07858	1083	.92142		10
7	00	9.08589	1041	9.99675	15	9.08914	1056	10.91086	83	00
	10	.09606	1017	.99659	16	.09947	1033	.90053		50
	20	.10599	993	.99643	16	.10956	1009	.89044		40
	30	.11570	971	.99627	16	.11943	987	.88057		30
	40	.12519	949	.99610	17	.12909	966	.87091		20
	50	.13447	928	.99593	17	.13854	945	.86146		10
8	00	9.14355	908	9.99575	18	9.14780	926	10.85220	82	00
	10	.15245	890	.99557	18	.15688	908	.84312		50
	20	.16116	871	.99539	18	.16577	889	.83423		40
	30	.16970	854	.99520	19	.17450	873	.82550		30
	40	.17807	837	.99501	19	.18306	856	.81694		20
	50	.18628	821	.99482	19	.19146	840	.80854		10
9	00	9.19433	805	9.99462	20	9.19971	825	10.80029	81	00
	10	.20223	790	.99442	20	.20782	811	.79218		50
	20	.20999	776	.99421	21	.21578	796	.78422		40
	30	.21761	762	.99400	21	.22361	783	.77639		30
	40	.22509	748	.99379	21	.23130	769	.76870		20
	50	.23244	735	.99357	22	.23887	757	.76113		10
10	00	9.23967	723	9.99335	22	9.24632	745	10.75368	80	00
	10	.24677	710	.99313	22	.25365	733	.74635		50
	20	.25376	699	.99290	23	.26086	721	.73914		40
	30	.26063	687	.99267	23	.26797	711	.73203		30
	40	.26739	676	.99243	24	.27496	699	.72504		20
	50	.27405	636	.99219	24	.28186	690	.71814		10
11	00	9.28060	655	9.99195	24	9.28865	679	10.71135	79	00
	10	.28705	645	.99170	25	.29535	670	.70465		50
	20	.29340	635	.99145	25	.30195	660	.69805		40
	30	.29965	625	.90119	26	.30846	651	.69151		30
	40	.30582	617	.99093	26	.31488	642	.68511		20
	50	.31189	607	.99067	26	.32122	634	.67878		10
12	00	9.31788	599	9.99040	27	9.32747	625	10.67252	78	00
	10	.32378	590	.99013	27	.33365	618	.66635		50
		.32960	582	.98986	27	.33974	609	.66026		40
		.33534	574	.98958	28	.34575	601	.65424		30
		.34100	566	.98930	28	.35170	595	.64830		20
		.34658	558	.98901	29	.35757	587	.64243		10
		ine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—Contd.

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
13	00	9.35209	551	9.98872	29	9.36336	579	10.63664	77	00
	10	.35752	543	.98843	29	.36909	573	.63091		50
	20	.36289	537	.98813	30	.37476	567	.62524		40
	30	.36818	528	.98783	30	.38035	559	.61965		30
	40	.37341	523	.98753	30	.38589	554	.61411		20
	50	.37858	517	.98722	31	.39136	547	.60864		10
14	00	9.38367	509	9.98690	32	9.39677	541	10.60323	76	00
	10	.38871	504	.98659	31	.40212	535	.59788		50
	20	.39368	497	.98627	32	.40742	530	.59258		40
	30	.39860	492	.98594	33	.41266	524	.58734		30
	40	.40345	485	.98561	33	.41784	518	.58216		20
	50	.40825	480	.98528	33	.42297	513	.57703		10
15	00	9.41300	475	9.98494	34	9.42805	508	10.57195	75	00
	10	.41768	468	.98460	34	.43308	503	.56692		50
	20	.42232	464	.98426	34	.43806	498	.56194		40
	30	.42690	458	.98391	35	.44299	493	.55701		30
	40	.43143	453	.98356	35	.44787	488	.55213		20
	50	.43591	448	.98320	36	.45271	484	.54729		10
16	00	9.44034	443	9.98284	36	9.45750	479	10.54250	74	00
	10	.44472	438	.98248	36	.46224	474	.53776		50
	20	.44905	433	.98211	37	.46694	470	.53305		40
	30	.45334	429	.98174	37	.47160	466	.52839		30
	40	.45758	424	.98136	38	.47622	462	.52378		20
	50	.46178	420	.98098	38	.48080	458	.51920		10
17	00	9.46593	415	9.98060	38	9.48534	454	10.51466	73	00
	10	.47005	412	.98021	39	.48984	450	.51016		50
	20	.47411	406	.97982	39	.49430	446	.50570		40
	30	.47814	403	.97942	40	.49872	442	.50128		30
	40	.48213	399	.97902	40	.50311	439	.49689		20
	50	.48607	394	.97861	41	.50746	435	.49254		10
18	00	9.48998	391	9.97821	40	9.51178	432	10.48822	72	00
	10	.49385	387	.97779	42	.51606	428	.48394		50
	20	.49768	383	.97738	41	.52030	424	.47969		40
	30	.50148	380	.97696	42	.52452	422	.47548		30
	40	.50523	375	.97653	43	.52870	418	.47130		20
	50	.50896	373	.97610	43	.53285	415	.46715		10
19	00	9.51264	368	9.97567	43	9.53697	412	10.46303	71	00
	10	.51629	365	.97523	44	.54106	409	.45894		50
	20	.51991	362	.97479	44	.54512	406	.45488		40
	30	.52349	358	.97435	44	.54915	403	.45085		30
	40	.52705	356	.97390	45	.55315	400	.44685		20
	50	.53056	351	.97344	46	.55712	397	.44288		10
20	00	9.53405	349	9.97299	45	9.56107	395	10.43893	70	00
	10	.53751	346	.97252	47	.56498	391	.43502		50
	20	.54093	342	.97206	46	.56887	389	.43113		40
	30	.54432	339	.97159	47	.57274	387	.42726		30
	40	.54769	337	.97111	48	.57658	384	.42342		20
	50	.55102	333	.97063	48	.58039	381	.41961		10
21	00	9.55433	331	9.97015	48	9.58418	379	10.41582	69	00
	10	.55761	328	.96966	49	.58794	376	.41206		50
	20	.56085	324	.96917	49	.59168	374	.40832		40
	30	.56407	322	.96868	49	.59540	372	.40460		30
	40	.56727	320	.96818	50	.59909	369	.40091		20
	50	.57043	316	.96767	51	.60276	367	.39724		10
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.		

TABLE XIV—**Common logarithms of circular functions**—Contd.

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
22	00	9.57357	314	9.96717	50	9.60641	365	10.39359	68	00
	10	.57669	312	.96665	52	.61004	363	.38996		50
	20	.57978	309	.96614	51	.61364	360	.38636		40
	30	.58284	306	.96561	53	.61722	358	.38278		30
	40	.58588	304	.96509	52	.62079	357	.37921		20
	50	.58889	301	.96456	53	.62433	354	.37567		10
23	00	9.59188	299	9.96403	53	9.62785	352	10.37215	67	00
	10	.59484	296	.96349	54	.63135	350	.36864		50
	20	.59778	294	.96294	55	.63484	349	.36516		40
	30	.60070	292	.96240	54	.63830	346	.36170		30
	40	.60359	289	.96185	55	.64175	345	.35825		20
	50	.60646	287	.96129	56	.64517	342	.35483		10
24	00	9.60931	285	9.96073	56	9.64858	341	10.35142	66	00
	10	.61214	283	.96016	57	.65197	339	.34803		50
	20	.61494	280	.95960	56	.65535	338	.34465		40
	30	.61773	279	.95902	58	.65870	335	.34130		30
	40	.62049	276	.95844	58	.66204	334	.33796		20
	50	.62323	274	.95786	58	.66537	333	.33463		10
25	00	9.62595	272	9.95728	58	9.66867	330	10.33133	65	00
	10	.62865	270	.95668	60	.67196	329	.32804		50
	20	.63133	268	.95609	59	.67524	328	.32476		40
	30	.63398	265	.95549	60	.67850	326	.32150		30
	40	.63662	264	.95488	61	.68174	324	.31826		20
	50	.63924	262	.95427	61	.68497	323	.31503		10
26	00	9.64184	260	9.95366	60	9.68818	321	10.31182	64	00
	10	.64442	258	.95304	62	.69138	320	.30862		50
	20	.64698	256	.95242	62	.69457	319	.30543		40
	30	.64953	255	.95179	63	.69774	317	.30226		30
	40	.65205	252	.95116	63	.70089	315	.29911		20
	50	.65456	251	.95052	64	.70404	315	.29596		10
27	00	9.65705	249	9.94988	64	9.70717	313	10.29283	63	00
	10	.65952	247	.94923	65	.71028	311	.28972		50
	20	.66197	245	.94858	65	.71339	311	.28661		40
	30	.66441	244	.94793	65	.71648	309	.28352		30
	40	.66682	241	.94727	66	.71955	307	.28044		20
	50	.66922	240	.94660	67	.72262	307	.27738		10
28	00	9.67161	239	9.94593	67	9.72567	305	10.27433	62	00
	10	.67398	237	.94526	67	.72872	305	.27128		50
	20	.67633	235	.94458	68	.73175	303	.26825		40
	30	.67866	233	.94390	68	.73476	301	.26524		30
	40	.68098	232	.94321	69	.73777	301	.26223		20
	50	.68328	230	.94252	69	.74077	300	.25923		10
29	00	9.68557	229	9.94182	70	9.74375	298	10.25625	61	00
	10	.68784	227	.94112	70	.74673	298	.25327		50
	20	.69010	226	.94041	71	.74969	296	.25031		40
	30	.69234	224	.93970	71	.75264	295	.24736		30
	40	.69456	222	.93898	72	.75558	294	.24441		20
	50	.69677	221	.93826	72	.75852	294	.24148		10
30	00	9.69897	220	9.93753	73	9.76144	292	10.23856	60	00
		.70115	218	.93680	73	.76435	291	.23565		50
		.70332	217	.93606	74	.76725	290	.23274		40
		.70547	215	.93532	74	.77015	290	.22985		30
		.70761	214	.93457	75	.77303	288	.22697		20
		.70973	212	.93382	75	.77591	288	.22409		10
		ne.	*Diff.*	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

TABLE XIV—**Common logarithms of circular functions**—Contd.

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′									
31	00	9.71184	211	9.93307	75	9.77877	286	10.22123	59	00
	10	.71393	209	.93230	77	.78163	286	.21837		50
	20	.71602	209	.93154	76	.78448	285	.21552		40
	30	.71808	206	.93077	77	.78732	284	.21268		30
	40	.72014	206	.92999	78	.79015	283	.20985		20
	50	.72218	204	.92921	78	.79297	282	.20703		10
32	00	9.72421	203	9.92842	79	9.79579	282	10.20421	58	00
	10	.72622	201	.92763	79	.79860	281	.20140		50
	20	.72823	201	.92683	80	.80140	280	.19860		40
	30	.73022	199	.92603	80	.80419	279	.19581		30
	40	.73219	197	.92522	81	.80697	278	.19303		20
	50	.73416	197	.92441	81	.80975	278	.19025		10
33	00	9.73611	195	9.92359	82	9.81252	277	10.18748	57	00
	10	.73805	194	.92277	82	.81528	276	.18472		50
	20	.73997	192	.92194	83	.81803	275	.18196		40
	30	.74189	192	.92111	83	.82078	275	.17922		30
	40	.74379	190	.92027	84	.82352	274	.17648		20
	50	.74568	189	.91942	85	.82626	274	.17374		10
34	00	9.74756	188	9.91857	85	9.82899	273	10.17101	56	00
	10	.74943	187	.91772	85	.83171	272	.16829		50
	20	.75128	185	.91686	86	.83442	271	.16557		40
	30	.75313	185	.91599	87	.83713	271	.16287		30
	40	.75496	183	.91512	87	.83984	271	.16016		20
	50	.75678	182	.91425	87	.84253	269	.15746		10
35	00	9.75859	181	9.91336	89	9.84523	270	10.15477	55	00
	10	.76039	180	.91248	88	.84791	268	.15209		50
	20	.76218	179	.91158	90	.85059	268	.14941		40
	30	.76395	177	.91069	89	.85327	268	.14673		30
	40	.76572	177	.90978	91	.85594	267	.14406		20
	50	.76747	175	.90887	91	.85860	266	.14140		10
36	00	9.76922	175	9.90796	91	9.86126	266	10.13874	54	00
	10	.77095	173	.90704	92	.86391	265	.13608		50
	20	.77267	172	.90611	93	.86656	265	.13344		40
	30	.77439	172	.90518	93	.86921	265	.13079		30
	40	.77609	170	.90424	94	.87185	264	.12815		20
	50	.77778	169	.90330	94	.87448	263	.12552		10
37	00	9.77946	168	9.90235	95	9.87711	263	10.12289	53	00
	10	.78113	167	.90139	96	.87974	263	.12026		50
	20	.78280	167	.90043	96	.88236	262	.11764		40
	30	.78445	165	.89947	96	.88498	262	.11502		30
	40	.78609	164	.89849	98	.88759	261	.11241		20
	50	.78772	163	.89752	97	.89020	261	.10980		10
38	00	9.78934	162	9.89653	99	9.89281	261	10.10719	52	00
	10	.79095	161	.89554	99	.89541	260	.10459		50
	20	.79256	161	.89455	99	.89801	260	.10199		40
	30	.79415	159	.89354	101	.90060	259	.09939		30
	40	.79573	158	.89254	100	.90320	260	.09680		20
	50	.79731	158	.89152	102	.90578	258	.09421		10
39	00	9.79887	156	9.89050	102	9.90837	259	10.09163	51	00
	10	.80043	156	.88948	102	.91095	258	.08905		50
	20	.80197	154	.88844	104	.91353	258	.08647		40
	30	.80351	154	.88741	103	.91610	257	.08390		30
	40	.80504	153	.88636	105	.91868	258	.08132		20
	50	.80656	152	.88531	105	.92125	257	.07875		10
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tan		

TABLE XIV—Common logarithms of circular functions—Contd.

Arc.		Sine.	Diff.	Cosine.	Diff.	Tang.	Diff.	Cotang.		
°	′								°	′
40	00	9.80807	151	9.88425	106	9.92381	256	10.07618	50	00
	10	.80957	150	.88319	106	.92638	257	.07362		50
	20	.81106	149	.88212	107	.92894	256	.07106		40
	30	.81254	148	.88105	107	.93150	256	.06850		30
	40	.81402	148	.87996	109	.93406	256	.06594		20
	50	.81548	146	.87887	109	.93661	255	.06339		10
41	00	9.81694	146	9.87778	109	9.93916	255	10.06084	49	00
	10	.81839	145	.87668	110	.94171	255	.05829		50
	20	.81983	144	.87557	111	.94426	255	.05574		40
	30	.82126	143	.87446	111	.94681	255	.05319		30
	40	.82269	143	.87333	113	.94935	254	.05065		20
	50	.82410	141	.87221	112	.95190	255	.04810		10
42	00	9.82551	141	9.87107	114	9.95444	254	10.04556	48	00
	10	.82691	140	.86993	114	.95698	254	.04302		50
	20	.82830	139	.86878	115	.95952	254	.04048		40
	30	.82968	138	.86763	115	.96205	253	.03795		30
	40	.83106	138	.86647	116	.96459	254	.03541		20
	50	.83242	136	.86530	117	.96712	253	.03288		10
43	00	9.83378	136	9.86413	117	9.96966	254	10.03034	47	00
	10	.83513	135	.86295	118	.97219	253	.02781		50
	20	.83648	135	.86176	119	.97472	253	.02528		40
	30	.83781	133	.86056	120	.97725	253	.02275		30
	40	.83914	133	.85936	120	.97978	253	.02022		20
	50	.84046	132	.85815	121	.98231	253	.01769		10
44	00	9.84177	131	9.85693	122	9.98484	253	10.01516	46	00
	10	.84308	131	.85571	122	.98736	252	.01263		50
	20	.84437	129	.85448	123	.98989	253	.01011		40
	30	.84566	129	.85324	124	.99242	253	.00758		30
	40	.84694	128	.85200	124	.99495	253	.00505		20
	50	.84822	128	.85074	126	.99747	252	.00253		10
45	00	9.84948	126	9.84948	126	10.00000	253	10.00000	45	00
		Cosine.	Diff.	Sine.	Diff.	Cotang.	Diff.	Tang.	Arc.	

114. **The slide rule** is a contrivance for using logs. mechanically. It consists (fig. 47) of a rule, in the middle of which is a slide. The edges of the groove and the edges of the slide are graduated, forming four scales, called A, B, C, and D. An indicator, which can be set at any point, guides the eye in selecting opposite numbers. The slide rule deals with **mantissas** only. Characteristics must be obtained by inspection.

To multiply.—Move the slide to the *right* until 1 on scale B is opposite the smaller of the 2 numbers on A; the number on A opposite the larger of the 2 numbers on B is the product.

To divide.—Move the slide to the *left* until the *divisor* on B is under 1 on A. The number on A opposite the *dividend* on B is the quotient desired. **To multiply and divide simultaneously,** or to **solve a proportion,** set the divisor on B opposite one of the other numbers on A. The number on A opposite the third number on B is the result desired.

To find the square of a number.—Take the number on A opposite the given number on D.

To find the square root.—Take the number on D opposite the given number on A. In taking square roots use only the *left half* of A, for an odd number of figures in front of the decimal point, and the *right half* only for *even* number.

To find a cube.—Set 1 on B opposite the given number on D. The number on A opposite the given number on B is the cube desired.

To find a cube root.—Take the root approximately by inspection. Set this number on B opposite the given number on A. Note whether 1 on C is opposite the approximate root on D. If so, the approximate root is the correct one; if not, move the slide slightly one way or the other until the number on B opposite the given number, and the number on D opposite the one on C are the same. This number is the desired cube root.

Occasional users of the slide rule will do well to adhere to the simple operations above described. Regular users will study the theory and scope of the rule from one of the several treatises on the subject.

TABLE XV.

115. **Table of squares, cubes, square roots, and cube roots** of numbers from 1 to 1,000:

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
1	1	1	1.	1.	51	2601	132651	7.1414	3.7084
2	4	8	1.4142	1.2599	52	2704	140608	7.2111	3.7325
3	9	27	1.7321	1.4422	53	2809	148877	7.2801	3.7563
4	16	64	2.0000	1.5874	54	2916	157464	7.3485	3.7798
5	25	125	2.2361	1.7100	55	3025	166375	7.4162	3.8030
6	36	216	2.4495	1.8171	56	3136	175616	7.4833	3.8259
7	49	343	2.6458	1.9129	57	3249	185193	7.5498	3.8485
8	64	512	2.8284	2.0000	58	3364	195112	7.6158	3.8709
9	81	729	3.0000	2.0801	59	3481	205379	7.6811	3.8930
10	100	1000	3.1623	2.1544	60	3600	216000	7.7460	3.9149
11	121	1331	3.3166	2.2240	61	3721	226981	7.8102	3.9365
12	144	1728	3.4641	2.2894	62	3844	238328	7.8740	3.9579
13	169	2197	3.6056	2.3513	63	3969	250047	7.9373	3.9791
14	196	2744	3.7417	2.4101	64	4096	262144	8.	4.
15	225	3375	3.8730	2.4662	65	4225	274625	8.0623	4.0207
16	256	4096	4.	2.5198	66	4356	287496	8.1240	4.0412
17	289	4913	4.1231	2.5713	67	4489	300763	8.1854	4.0615
18	324	5832	4.2426	2.6207	68	4624	314432	8.2462	4.0817
19	361	6859	4.3589	2.6684	69	4761	328509	8.3066	4.1016
20	400	8000	4.4721	2.7144	70	4900	343000	8.3666	4.1213
21	441	9261	4.5826	2.7589	71	5041	357911	8.4261	4.1408
22	484	10648	4.6904	2.8020	72	5184	373248	8.4853	4.1602
23	529	12167	4.7958	2.8439	73	5329	389017	8.5440	4.1793
24	576	13824	4.8990	2.8845	74	5476	405224	8.6023	4.1983
25	625	15625	5.	2.9240	75	5625	421875	8.6603	4.2172
26	676	17576	5.0990	2.9625	76	5776	438976	8.7178	4.2358
27	729	19683	5.1962	3.0000	77	5929	456533	8.7750	4.2543
28	784	21952	5.2915	3.0366	78	6084	474552	8.8318	4.2727
29	841	24389	5.3852	3.0723	79	6241	493039	8.8882	4.2908
30	900	27000	5.4772	3.1072	80	6400	512000	8.9443	4.3089
31	961	29791	5.5678	3.1414	81	6561	531441	9.	4.3267
32	1024	32768	5.6569	3.1748	82	6724	551368	9.0554	4.3445
33	1089	35937	5.7446	3.2075	83	6889	571787	9.1104	4.3621
34	1156	39304	5.8310	3.2396	84	7056	592704	9.1652	4.3795
35	1225	42875	5.9161	3.2711	85	7225	614125	9.2195	4.3968
36	1296	46656	6.	3.3019	86	7396	636056	9.2736	4.4140
37	1369	50653	6.0828	3.3322	87	7569	658503	9.3274	4.4310
38	1444	54872	6.1644	3.3620	88	7744	681472	9.3808	4.4480
39	1521	59319	6.2450	3.3912	89	7921	704969	9.4340	4.4647
40	1600	64000	6.3246	3.4200	90	8100	729000	9.4868	4.4814
41	1681	68921	6.4031	3.4482	91	8281	753571	9.5394	4.4979
42	1764	74088	6.4807	3.4760	92	8464	778688	9.5917	4.5144
43	1849	79507	6.5574	3.5034	93	8649	804357	9.6437	4.5307
44	1936	85184	6.6332	3.5303	94	8836	830584	9.6954	4.5468
45	2025	91125	6.7082	3.5569	95	9025	857375	9.7468	4.5629
46	2116	97336	6.7823	3.5830	96	9216	884736	9.7980	4.5789
47	2209	103823	6.8557	3.6088	97	9409	912673	9.8489	4.5947
48	2304	110592	6.9282	3.6342	98	9604	941192	9.8995	4.6104
49	2401	117649	7.	3.6593	99	9801	970299	9.9499	4.6261
	2500	*125000*	7.0711	3.6840	100	10000	1000000	10.	4.6416

TABLE XV.—**Table of squares, cubes, square roots, and cube roots**—Continued.

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
101	10201	1030301	10.0499	4.6570	151	22801	3442951	12.2882	5.3251
102	10404	1061208	10.0995	4.6723	152	23104	3511808	12.3288	5.3368
103	10609	1092727	10.1489	4.6875	153	23409	3581577	12.3693	5.3485
104	10816	1124864	10.1980	4.7027	154	23716	3652264	12.4097	5.3601
105	11025	1157625	10.2470	4.7177	155	24025	3723875	12.4499	5.3717
106	11236	1191016	10.2956	4.7326	156	24336	3796416	12.4900	5.3832
107	11449	1225043	10.3441	4.7475	157	24649	3869893	12.5300	5.3947
108	11664	1259712	10.3923	4.7622	158	24964	3944312	12.5698	5.4061
109	11881	1295029	10.4403	4.7769	159	25281	4019679	12.6095	5.4175
110	12100	1331000	10.4881	4.7914	160	25600	4096000	12.6491	5.4288
111	12321	1367631	10.5357	4.8059	161	25921	4173281	12.6886	5.4401
112	12544	1404928	10.5830	4.8203	162	26244	4251528	12.7279	5.4514
113	12769	1442897	10.6301	4.8346	163	26569	4330747	12.7671	5.4626
114	12996	1481544	10.6771	4.8488	164	26896	4410944	12.8062	5.4737
115	13225	1520875	10.7238	4.8629	165	27225	4492125	12.8452	5.4848
116	13456	1560896	10.7703	4.8770	166	27556	4574296	12.8841	5.4959
117	13689	1601613	10.8167	4.8910	167	27889	4657463	12.9228	5.5069
118	13924	1643032	10.8628	4.9049	168	28224	4741632	12.9615	5.5178
119	14161	1685159	10.9087	4.9187	169	28561	4826809	13	5.5288
120	14400	1728000	10.9545	4.9324	170	28900	4913000	13.0384	5.5397
121	14641	1771561	11.0000	4.9461	171	29241	5000211	13.0767	5.5505
122	14884	1815848	11.0454	4.9597	172	29584	5088448	13.1149	5.5613
123	15129	1860867	11.0905	4.9732	173	29929	5177717	13.1529	5.5721
124	15376	1906624	11.1355	4.9866	174	30276	5268024	13.1909	5.5828
125	15625	1953125	11.1803	5	175	30625	5359375	13.2288	5.5934
126	15876	2000376	11.2250	5.0133	176	30976	5451776	13.2665	5.6041
127	16129	2048383	11.2694	5.0265	177	31329	5545233	13.3041	5.6147
128	16384	2097152	11.3137	5.0397	178	31684	5639752	13.3417	5.6252
129	16641	2146689	11.3578	5.0528	179	32041	5735339	13.3791	5.6357
130	16900	2197000	11.4018	5.0658	180	32400	5832000	13.4164	5.6462
131	17161	2248091	11.4455	5.0788	181	32761	5929741	13.4536	5.6567
132	17424	2299968	11.4891	5.0916	182	33124	6028568	13.4907	5.6671
133	17689	2352637	11.5326	5.1045	183	33489	6128487	13.5277	5.6774
134	17956	2406104	11.5758	5.1172	184	33856	6229504	13.5647	5.6877
135	18225	2460375	11.6190	5.1299	185	34225	6331625	13.6015	5.6980
136	18496	2515456	11.6619	5.1426	186	34596	6434856	13.6382	5.7083
137	18769	2571353	11.7047	5.1551	187	34969	6539203	13.6748	5.7185
138	19044	2628072	11.7473	5.1676	188	35344	6644672	13.7113	5.7287
139	19321	2685619	11.7898	5.1801	189	35721	6751269	13.7477	5.7388
140	19600	2744000	11.8322	5.1925	190	36100	6859000	13.7840	5.7489
141	19881	2803221	11.8743	5.2048	191	36481	6967871	13.8203	5.7590
142	20164	2863288	11.9164	5.2171	192	36864	7077888	13.8564	5.7690
143	20449	2924207	11.9583	5.2293	193	37249	7189057	13.8924	5.7790
144	20736	2985984	12	5.2415	194	37636	7301384	13.9284	5.7890
145	21025	3048625	12.0416	5.2536	195	38025	7414875	13.9642	5.7989
146	21316	3112136	12.0830	5.2656	196	38416	7529536	14	5.8088
147	21609	3176523	12.1244	5.2776	197	38809	7645373	14.0357	5.8186
148	21904	3241792	12.1655	5.2896	198	39204	7762392	14.0712	5.8285
149	22201	3307949	12.2066	5.3015	199	39601	7880599	14.1067	5.8383
150	22500	3375000	12.2474	5.3133	200	40000	8000000	14.1421	5.8480

TABLE XV.—**Table of squares, cubes, square roots, and cube roots**—Continued.

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
201	40401	8120601	14.1774	5.8578	251	63001	15813251	15.8430	6.3080
202	40804	8242408	14.2127	5.8675	252	63504	16003008	15.8745	6.3164
203	41209	8365427	14.2478	5.8771	253	64009	16194277	15.9060	6.3247
204	41616	8489664	14.2829	5.8868	254	64516	16387064	15.9374	6.3330
205	42025	8615125	14.3178	5.8964	255	65025	16581375	15.9687	6.3413
206	42436	8741816	14.3527	5.9059	256	65536	16777216	16	6.3496
207	42849	8869743	14.3875	5.9155	257	66049	16974593	16.0312	6.3579
208	43264	8998912	14.4222	5.9250	258	66564	17173512	16.0624	6.3661
209	43681	9129329	14.4568	5.9345	259	67081	17373979	16.0935	6.3743
210	44100	9261000	14.4914	5.9439	260	67600	17576000	16.1245	6.3825
211	44521	9393931	14.5258	5.9533	261	68121	17779581	16.1555	6.3907
212	44944	9528128	14.5602	5.9627	262	68644	17984728	16.1864	6.3988
213	45369	9663597	14.5945	5.9721	263	69169	18191447	16.2173	6.4070
214	45796	9800344	14.6287	5.9814	264	69696	18399744	16.2481	6.4151
215	46225	9938375	14.6629	5.9907	265	70225	18609625	16.2788	6.4232
216	46656	10077696	14.6969	6	266	70756	18821096	16.3095	6.4312
217	47089	10218313	14.7309	6.0092	267	71289	19034163	16.3401	6.4393
218	47524	10360232	14.7648	6.0185	268	71824	19248832	16.3707	6.4473
219	47961	10503459	14.7986	6.0277	269	72361	19465109	16.4012	6.4553
220	48400	10648000	14.8324	6.0368	270	72900	19683000	16.4317	6.4633
221	48841	10793861	14.8661	6.0459	271	73441	19902511	16.4621	6.4713
222	49284	10941048	14.8997	6.0550	272	73984	20123648	16.4924	6.4792
223	49729	11089567	14.9332	6.0641	273	74529	20346417	16.5227	6.4872
224	50176	11239424	14.9666	6.0732	274	75076	20570824	16.5529	6.4951
225	50625	11390625	15	6.0822	275	75625	20796875	16.5831	6.5030
226	51076	11543176	15.0333	6.0912	276	76176	21024576	16.6132	6.5108
227	51529	11697083	15.0665	6.1002	277	76729	21253933	16.6433	6.5187
228	51984	11852352	15.0997	6.1091	278	77284	21484952	16.6733	6.5265
229	52441	12008989	15.1327	6.1180	279	77841	21717639	16.7033	6.5343
230	52900	12167000	15.1658	6.1269	280	78400	21952000	16.7332	6.5421
231	53361	12326391	15.1987	6.1358	281	78961	22188041	16.7631	6.5499
232	53824	12487168	15.2315	6.1446	282	79524	22425768	16.7929	6.5577
233	54289	12649337	15.2643	6.1534	283	80089	22665187	16.8226	6.5654
234	54756	12812904	15.2971	6.1622	284	80656	22906304	16.8523	6.5731
235	55225	12977875	15.3297	6.1710	285	81225	23149125	16.8819	6.5808
236	55696	13144256	15.3623	6.1797	286	81796	23393656	16.9115	6.5885
237	56169	13312053	15.3948	6.1885	287	82369	23639903	16.9411	6.5962
238	56644	13481272	15.4272	6.1972	288	82944	23887872	16.9706	6.6039
239	57121	13651919	15.4596	6.2058	289	83521	24137569	17	6.6115
240	57600	13824000	15.4919	6.2145	290	84100	24389000	17.0294	6.6191
241	58081	13997521	15.5242	6.2231	291	84681	24642171	17.0587	6.6267
242	58564	14172488	15.5563	6.2317	292	85264	24897088	17.0880	6.6343
243	59049	14348907	15.5885	6.2403	293	85849	25153757	17.1172	6.6419
244	59536	14526784	15.6205	6.2488	294	86436	25412184	17.1464	6.6494
245	60025	14706125	15.6525	6.2573	295	87025	25672375	17.1756	6.6569
246	60516	14886936	15.6844	6.2658	296	87616	25934336	17.2047	6.6644
247	61009	15069223	15.7162	6.2743	297	88209	26198073	17.2337	6.6719
248	61504	15252992	15.7480	6.2828	298	88804	26463592	17.2627	6.6794
249	62001	15438249	15.7797	6.2912	299	89401	26730899	17.2916	6.6869
	500	15625000	15.8114	6.2996	300	90000	27000000	17.3205	6.6943

TABLE XV.—**Table of squares, cubes, square roots, and cube roots.**—Continued.

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
301	90601	27270901	17.3494	6.7018	351	123201	43243551	18.7350	7.0540
302	91204	27543608	17.3781	6.7092	352	123904	43614208	18.7617	7.0607
303	91809	27818127	17.4069	6.7166	353	124609	43986977	18.7883	7.0674
304	92416	28094464	17.4356	6.7240	354	125316	44361864	18.8149	7.0740
305	93025	28372625	17.4642	6.7313	355	126025	44738875	18.8414	7.0807
306	93636	28652616	17.4929	6.7387	356	126736	45118016	18.8680	7.0873
307	94249	28934443	17.5214	6.7460	357	127449	45499293	18.8944	7.0940
308	94864	29218112	17.5499	6.7533	358	128164	45882712	18.9209	7.1006
309	95481	29503629	17.5784	6.7606	359	128881	46268279	18.9473	7.1072
310	96100	29791000	17.6068	6.7679	360	129600	46656000	18.9737	7.1138
311	96721	30080231	17.6352	6.7752	361	130321	47045881	19	7.1204
312	97344	30371328	17.6635	6.7824	362	131044	47437928	19.0263	7.1269
313	97969	30664297	17.6918	6.7897	363	131769	47832147	19.0526	7.1335
314	98596	30959144	17.7200	6.7969	364	132496	48228544	19.0788	7.1400
315	99225	31255875	17.7482	6.8041	365	133225	48627125	19.1050	7.1466
316	99856	31554496	17.7764	6.8113	366	133956	49027896	19.1311	7.1531
317	100489	31855013	17.8045	6.8185	367	134689	49430863	19.1572	7.1596
318	101124	32157432	17.8326	6.8256	368	135424	49836032	19.1833	7.1661
319	101761	32461759	17.8606	6.8328	369	136161	50243409	19.2094	7.1726
320	102400	32768000	17.8885	6.8399	370	136900	50653000	19.2354	7.1791
321	103041	33076161	17.9165	6.8470	371	137641	51064811	19.2614	7.1855
322	103684	33386248	17.9444	6.8541	372	138384	51478848	19.2873	7.1920
323	104329	33698267	17.9722	6.8612	373	139129	51895117	19.3132	7.1984
324	104976	34012224	18	6.8683	374	139876	52313624	19.3391	7.2048
325	105625	34328125	18.0278	6.8753	375	140625	52734375	19.3649	7.2112
326	106276	34645976	18.0555	6.8824	376	141376	53157376	19.3907	7.2177
327	106929	34965783	18.0831	6.8894	377	142129	53582633	19.4165	7.2240
328	107584	35287552	18.1108	6.8964	378	142884	54010152	19.4422	7.2304
329	108241	35611289	18.1384	6.9034	379	143641	54439939	19.4679	7.2368
330	108900	35937000	18.1659	6.9104	380	144400	54872000	19.4936	7.2432
331	109561	36264691	18.1934	6.9174	381	145161	55306341	19.5192	7.2495
332	110224	36594368	18.2209	6.9244	382	145924	55742968	19.5448	7.2558
333	110889	36926037	18.2483	6.9313	383	146689	56181887	19.5704	7.2622
334	111556	37259704	18.2757	6.9382	384	147456	56623104	19.5959	7.2685
335	112225	37595375	18.3030	6.9451	385	148225	57066625	19.6214	7.2748
336	112896	37933056	18.3303	6.9521	386	148996	57512456	19.6469	7.2811
337	113569	38272753	18.3576	6.9589	387	149769	57960603	19.6723	7.2874
338	114244	38614472	18.3848	6.9658	388	150544	58411072	19.6977	7.2936
339	114921	38958219	18.4120	6.9727	389	151321	58863869	19.7231	7.2999
340	115600	39304000	18.4391	6.9795	390	152100	59319000	19.7484	7.3061
341	116281	39651821	18.4662	6.9864	391	152881	59776471	19.7737	7.3124
342	116964	40001688	18.4932	6.9932	392	153664	60236288	19.7990	7.3186
343	117649	40353607	18.5203	7	393	154449	60698457	19.8242	7.3248
344	118336	40707584	18.5472	7.0068	394	155236	61162984	19.8494	7.3310
345	119025	41063625	18.5742	7.0136	395	156025	61629875	19.8746	7.3372
346	119716	41421736	18.6011	7.0203	396	156816	62099136	19.8997	7.3434
347	120409	41781923	18.6279	7.0271	397	157609	62570773	19.9249	7.3496
348	121104	42144192	18.6548	7.0338	398	158404	63044792	19.9499	7.3558
349	121801	42508549	18.6815	7.0406	399	159201	63521199	19.9750	7.3619
350	122500	42875000	18.7083	7.0473	400	160000	64000000	20	7.3681

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	481	231361	111284641	21.9317	7.8352
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	482	232324	111980168	21.9545	7.8406
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	483	233289	112678587	21.9773	7.8460
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	484	234256	113379904	22	7.8514
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	485	235225	114084125	22.0227	7.8568
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	486	236196	114791256	22.0454	7.8622
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	487	237169	115501303	22.0681	7.8676
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	488	238144	116214272	22.0907	7.8730
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	489	239121	116930169	22.1133	7.8784
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	490	240100	117649000	22.1359	7.8837
[illegible]	[illegible]	[illegible]	21	7.6117	491	241081	118370771	22.1585	7.8891
[illegible]	[illegible]	[illegible]	21.0238	7.6174	492	242064	119095488	22.1811	7.8944
[illegible]	[illegible]	[illegible]	21.0476	7.6232	493	243049	119823157	22.2036	7.8998
[illegible]	[illegible]	[illegible]	21.0713	7.6289	494	244036	120553784	22.2261	7.9051
[illegible]	[illegible]	88121125	21.0950	7.6346	495	245025	121287375	22.2486	7.9105
[illegible]	[illegible]	88716536	21.1187	7.6403	496	246016	122023936	22.2711	7.9158
[illegible]	[illegible]	89314623	21.1424	7.6460	497	247009	122763473	22.2935	7.9211
[illegible]	[illegible]	89915392	21.1660	7.6517	498	248004	123505992	22.3159	7.9264
[illegible]	[illegible]	[illegible]	21.1896	7.6574	499	249001	124251499	22.3383	7.9317
[illegible]	[illegible]	91125000	21.2132	7.6631	500	250000	125000000	22.3607	7.9370

TABLE XV.—**Table of squares, cubes, square roots, and cube roots**—Continued.

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
501	251001	125751501	22.3830	7.9423	551	303601	167284151	23.4734	8.1982
502	252004	126506008	22.4054	7.9476	552	304704	168196608	23.4947	8.2031
503	253009	127263527	22.4277	7.9528	553	305809	169112377	23.5160	8.2081
504	254016	128024064	22.4499	7.9581	554	306916	170031464	23.5372	8.2130
505	255025	128787625	22.4722	7.9634	555	308025	170953875	23.5584	8.2180
506	256036	129554216	22.4944	7.9686	556	309136	171879616	23.5797	8.2229
507	257049	130323843	22.5167	7.9739	557	310249	172808693	23.6008	8.2278
508	258064	131096512	22.5389	7.9791	558	311364	173741112	23.6220	8.2327
509	259081	131872229	22.5610	7.9843	559	312481	174676879	23.6432	8.2377
510	260100	132651000	22.5832	7.9896	560	313600	175616000	23.6643	8.2426
511	261121	133432831	22.6053	7.9948	561	314721	176558481	23.6854	8.2475
512	262144	134217728	22.6274	8	562	315844	177504328	23.7065	8.2524
513	263169	135005697	22.6495	8.0052	563	316969	178453547	23.7276	8.2573
514	264196	135796744	22.6716	8.0104	564	318096	179406144	23.7487	8.2621
515	265225	136590875	22.6936	8.0156	565	319225	180362125	23.7697	8.2670
516	266256	137388096	22.7156	8.0208	566	320356	181321496	23.7908	8.2719
517	267289	138188413	22.7376	8.0260	567	321489	182284263	23.8118	8.2768
518	268324	138991832	22.7596	7.0311	568	322624	183250432	23.8328	8.2816
519	269361	139798359	22.7816	8.0363	569	323761	184220009	23.8537	8.2865
520	270400	140608000	22.8035	8.0415	570	324900	185193000	23.8747	8.2913
521	271441	141420761	22.8254	8.0466	571	326041	186169411	23.8956	8.2962
522	272484	142236648	22.8473	8.0517	572	327184	187149248	23.9165	8.3010
523	273529	143055667	22.8692	8.0569	573	328329	188132517	23.9374	8.3059
524	274576	143877824	22.8910	8.0620	574	329476	189119224	23.9583	8.3107
525	275625	144703125	22.9129	8.0671	575	330625	190109375	23.9792	8.3155
526	276676	145531576	22.9347	8.0723	576	331776	191102976	24	8.3203
527	277729	146363183	22.9565	8.0774	577	332929	192100033	24.0208	8.3251
528	278784	147197952	22.9783	8.0825	578	334084	193100552	24.0416	8.3300
529	279841	148035889	23	8.0876	579	335241	194104539	24.0624	8.3348
530	280900	148877000	23.0217	8.0927	580	336400	195112000	24.0832	8.3396
531	281961	149721291	23.0434	8.0978	581	337561	196122941	24.1039	8.3443
532	283024	150568768	23.0651	8.1028	582	338724	197137368	24.1247	8.3491
533	284089	151419437	23.0868	8.1079	583	339889	198155287	24.1454	8.3539
534	285156	152273304	23.1084	8.1130	584	341056	199176704	24.1661	8.3587
535	286225	153130375	23.1301	8.1180	585	342225	200201625	24.1868	8.3634
536	287296	153990656	23.1517	8.1231	586	343396	201230056	24.2074	8.3682
537	288369	154854153	23.1733	8.1281	587	344569	202262003	24.2281	8.3730
538	289444	155720872	23.1948	8.1332	588	345744	203297472	24.2487	8.3777
539	290521	156590819	23.2164	8.1382	589	346921	204336469	24.2693	8.3825
540	291600	157464000	23.2379	8.1433	590	348100	205379000	24.2899	8.3872
541	292681	158340421	23.2594	8.1483	591	349281	206425071	24.3105	8.3919
542	293764	159220088	23.2809	8.1533	592	350464	207474688	24.3311	8.3967
543	294849	160103007	23.3024	8.1583	593	351649	208527857	24.3516	8.4014
544	295936	160989184	23.3238	8.1633	594	352836	209584584	24.3721	8.4061
545	297025	161878625	23.3452	8.1683	595	354025	210644875	24.3926	8.4108
546	298116	162771336	23.3666	8.1733	596	355216	211708736	24.4131	8.4155
547	299209	163667323	23.3880	8.1783	597	356409	212776173	24.4336	8.4202
548	300304	164566592	23.4094	8.1833	598	357604	213847192	24.4540	8.4249
549	301401	165469149	23.4307	8.1882	599	358801	214921799	24.4745	8.4298
550	302500	166375000	23.4521	8.1932	600	360000	216000000	24.4949	8.43

TABLE XV.—**Table of squares, cubes, square roots, and cube roots**—Continued.

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
601	361201	217081801	24.5153	8.4390	651	423801	275894451	25.5147	8.6668
602	362404	218167208	24.5357	8.4437	652	425104	277167808	25.5343	8.6713
603	363609	219256227	24.5561	8.4484	653	426409	278445077	25.5539	8.6757
604	364816	220348864	24.5764	8.4530	654	427716	279726264	25.5734	8.6801
605	366025	221445125	24.5967	8.4577	655	429025	281011375	25.5930	8.6845
606	367236	222545016	24.6171	8.4623	656	430336	282300416	25.6125	8.6890
607	368449	223648543	24.6374	8.4670	657	431649	283593393	25.6320	8.6934
608	369664	224755712	24.6577	8.4716	658	432964	284890312	25.6515	8.6978
609	370881	225866529	24.6779	8.4763	659	434281	286191179	25.6710	8.7022
610	372100	226981000	24.6982	8.4809	660	435600	287496000	25.6905	8.7066
611	373321	228099131	24.7184	8.4856	661	436921	288804781	25.7099	8.7110
612	374544	229220928	24.7386	8.4902	662	438244	290117528	25.7994	8.7154
613	375769	230346397	24.7588	8.4948	663	439569	291434247	25.7488	8.7198
614	376996	231475544	24.7790	8.4994	664	440896	292754944	25.7682	8.7241
615	378225	232608375	24.7992	8.5040	665	442225	294079625	25.7876	8.7285
616	379456	233744896	24.8193	8.5086	666	443556	295408296	25.8070	8.7329
617	380689	234885113	24.8395	8.5132	667	444889	296740963	25.8263	8.7373
618	381924	236029032	24.8596	8.5178	668	446224	298077632	25.8457	8.7416
619	383161	237176659	24.8797	8.5224	669	447761	299418309	25.8650	8.7460
620	384400	238328000	24.8998	8.5270	670	418900	300763000	25.8844	8.7503
621	385641	239483061	24.9199	8.5316	671	450241	302111711	25.9037	8.7547
622	386884	240641848	24.9399	8.5362	672	451584	303464448	25.9230	8.7590
623	388129	241804367	24.9600	8.5408	673	452929	304821217	25.9422	8.7634
624	389376	242970624	24.9800	8.5453	674	454276	306182024	25.9615	8.7677
625	390625	244140625	25	8.5499	675	455625	307546875	25.9808	8.7721
626	391876	245314376	25.0200	8.5544	676	456976	308915776	26	8.7764
627	393129	246491883	25.0400	8.5590	677	458329	310288733	26.0192	8.7807
628	394384	247673152	25.0599	8.5635	678	459684	311665752	26.0384	8.7850
629	395641	248858189	25.0799	8.5681	679	461041	313046839	26.0576	8.7893
630	396900	250047000	25.0998	8.5726	680	462400	314432000	26.0768	8.7937
631	398161	251239591	25.1197	8.5772	681	463761	315821241	26.0960	8.7980
632	399424	252435968	25.1396	8.5817	682	465124	317214568	26.1151	8.8023
633	400689	253636137	25.1595	8.5862	683	466489	318611987	26.1343	8.8066
634	401956	254840104	25.1794	8.5907	684	467856	320013504	26.1534	8.8109
635	403225	256047875	25.1992	8.5952	685	469225	321419125	26.1725	8.8152
636	404496	257259456	25.2190	8.5997	686	470596	322828856	26.1916	8.8194
637	405769	258474853	25.2389	8.6043	687	471969	324242703	26.2107	8.8237
638	407044	259694072	25.2587	8.6088	688	473344	325660672	26.2298	8.8280
639	408321	260917119	25.2784	8.6132	689	474721	327082769	26.2488	8.8323
640	409600	262144000	25.2982	8.6177	690	476100	328509000	26.2679	8.8366
641	410881	263374721	25.3180	8.6222	691	477481	329939371	26.2869	8.8408
642	412164	264609288	25.3377	8.6267	692	478864	331373888	26.3059	8.8451
643	413449	265847707	25.3574	8.6312	693	[illegible]	332812557	26.3249	8.8493
644	414736	267089984	25.3772	8.6357	694	[illegible]	[illegible]	26.3439	8.8536
645	416025	268336125	25.3969	8.6401	695	[illegible]	[illegible]	[illegible]	8.8578
646	417316	269586136	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
647	418609	270840023	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
648	419904	272097792	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
649	421201	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
650	422500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE XV.—**Table of squares, cubes, square roots, and cube roots**—Continued.

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
701	491401	344472101	26.4764	8.8833	751	564001	423564751	27.4044	9.0896
702	492804	345948408	26.4953	8.8875	752	565504	425259008	27.4226	9.0937
703	494209	347428927	26.5141	8.8917	753	567009	426957777	27.4408	9.0977
704	495616	348913664	25.5330	8.8959	754	568516	428661064	27.4591	9.1017
705	497025	350402625	26.5518	8.9001	755	570025	430368375	27.4773	9.1057
706	498436	351895816	26.5707	8.9043	756	571536	432081216	27.4955	9.1098
707	499849	353393243	26.5895	8.9085	757	573049	433798093	27.5136	9.1138
708	501264	354894912	26.6083	8.9127	758	574564	435519512	27.5318	9.1178
709	502681	356400829	26.6271	8.9169	759	576081	437245479	27.5500	9.1218
710	504100	357911000	26.6458	8.9211	760	577600	438976000	27.5681	9.1258
711	505521	359425431	26.6646	8.9253	761	579121	440711081	27.5862	9.1298
712	506944	360944128	26.6833	8.9295	762	580644	442450728	27.6043	9.1338
713	508369	362467097	26.7021	8.9337	763	582169	444194947	27.6225	9.1378
714	509796	363994344	26.7208	8.9378	764	583696	445943744	27.6405	9.1418
715	511225	365525875	26.7395	8.9420	765	585225	447697125	27.6586	9.1458
716	512656	367061696	26.7582	8.9462	766	586756	449455096	27.6767	9.1498
717	514089	368601813	26.7769	8.9503	767	588289	451217663	27.6948	9.1537
718	515524	370146232	26.7955	8.9545	768	589824	452984832	27.7128	9.1577
719	516961	371694959	26.8142	8.9587	769	591361	454756609	27.7308	9.1617
720	518400	373248000	26.8328	8.9628	770	592900	456533000	27.7489	9.1657
721	519841	374805361	26.8514	8.9670	771	594441	458314011	27.7669	9.1696
722	521284	376367048	26.8701	8.9711	772	595984	460099648	27.7849	9.1736
723	522729	377933067	26.8887	8.9752	773	597529	461889917	27.8029	9.1775
724	524176	379503424	26.9072	8.9794	774	599076	463684824	27.8209	9.1815
725	525625	381078125	26.9258	8.9835	775	600625	465484375	27.8388	9.1855
726	527076	382657176	26.9444	8.9876	776	602176	467288576	27.8568	9.1894
727	528529	384240583	26.9629	8.9918	777	603729	469097433	27.8747	9.1933
728	529984	385828352	26.9815	8.9959	778	605284	470910952	27.8927	9.1973
729	531441	387420489	27	9	779	606841	472729139	27.9106	9.2012
730	532900	389017000	27.0185	9.0041	780	608400	474552000	27.9285	9.2052
731	534361	390617891	27.0370	9.0082	781	609961	476379541	27.9464	9.2091
732	535824	392223168	27.0555	9.0123	782	611524	478211768	27.9643	9.2130
733	537289	393832837	27.0740	9.0164	783	613089	480048687	27.9821	9.2170
734	538756	395446904	27.0924	9.0205	784	614656	481890304	28	9.2209
735	540225	397065375	27.1109	9.0246	785	616225	483736625	28.0179	9.2248
736	541696	398688256	27.1293	9.0287	786	617796	485587656	28.0357	9.2287
737	543169	400315553	27.1477	9.0328	787	619369	487443403	28.0535	9.2326
738	514644	401947272	27.1662	9.0369	788	620944	489303872	28.0713	9.2365
739	546121	403583419	27.1846	9.0410	789	622521	491169069	28.0891	9.2404
740	547600	405224000	27.2029	9.0450	790	624100	493039000	28.1069	9.2443
741	519081	406869021	27.2213	9.0491	791	625681	494913671	28.1247	9.2482
742	550564	408518488	27.2397	9.0532	792	627264	496793088	28.1425	9.2521
[illegible]	[illegible]	[illegible]	27.2580	9.0572	793	628849	498677257	28.1603	9.2560
[illegible]	[illegible]	[illegible]	27.2764	9.0613	794	630436	500566184	28.1780	9.2599
[illegible]	[illegible]	[illegible]	27.2947	9.0654	795	632025	502459875	28.1957	9.2638
[illegible]	[illegible]	[illegible]	[illegible]	9.0694	796	633616	504358336	28.2135	9.2677
[illegible]	[illegible]	[illegible]	[illegible]	9.0735	797	635209	506261573	28.2312	9.2716
[illegible]	[illegible]	[illegible]	[illegible]	9.0775	798	636804	508169592	28.2489	9.2754
[illegible]	[illegible]	[illegible]	[illegible]	9.0816	799	638401	510082399	28.2666	9.2793
[illegible]	[illegible]	[illegible]	[illegible]	9.0856	800	640000	512000000	28.2843	9.28

TABLE XV.—**Table of squares, cubes, square roots, and cube roots**—Continued.

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt
801	641601	13922401	28.3019	9.2870	851	722201	616295051	29.1719	9.4764
802	643204	15849608	28.3196	9.2909	852	722904	618470208	29.1890	9.4801
803	644809	517781627	28.3373	9.2948	853	725609	620650477	29.2062	9.4838
804	646416	517718464	28.3549	9.2980	854	729316	622835864	29.2233	9.4875
805	648025	521660125	28.3725	9.3025	855	731025	625026375	29.2204	9.4912
806	649636	523606616	28.3901	9.3063	856	732736	627222016	29.2575	9.4949
807	651249	525557943	28.4077	9.3102	857	734449	629422793	29.2746	9.4986
808	652864	527514112	28.4253	9.3140	858	736164	631628712	29.2916	9.5023
809	654481	529475129	28.4429	9.3179	859	737881	633839779	29.3087	9.5060
810	656100	531441000	28.4605	9.3217	860	739600	636056000	29.3258	9.5097
811	657721	533411731	28.4781	9.3255	861	741321	638277381	29.3428	9.5134
812	659344	535387328	28.4956	9.3294	862	743044	640503928	29.3598	9.5171
813	660969	537367797	28.5132	9.3332	863	744769	642735647	29.3769	9.5207
814	662596	539353144	28.5307	9.3370	864	746496	644972544	29.3939	9.5244
815	664225	541343375	28.5482	9.3408	865	748225	647214625	29.4109	9.5281
816	665856	543338496	28.5657	9.3447	866	749956	649461896	29.4279	9.5317
817	667489	545338513	28.5832	9.3485	867	751689	651714363	29.4449	9.5354
818	669124	547343432	28.6007	9.3523	868	753424	653972032	29.4618	9.5391
819	670761	549353259	28.6182	9.3561	869	755161	656234909	29.4788	9.5427
820	672400	551368000	28.6356	9.3599	870	756900	658503000	29.4958	9.5464
821	674041	533387661	28.6531	9.3637	871	758641	660776311	29.5127	9.5501
822	675684	555412248	28.6705	9.3675	872	760384	663054848	29.5296	9.5537
823	677329	557441767	28.6880	9.3713	873	762129	665338617	29.5466	9.5574
824	678976	559476224	28.7054	9.3751	874	763876	667627624	29.5635	9.5610
825	680625	561515625	28.7228	9.3789	875	765625	669921875	29.5804	9.5647
826	682276	563559976	28.7402	9.3827	876	767376	672221376	29.5973	9.5683
827	683929	565609283	28.7576	9.3865	877	769129	674526133	29.6142	9.5719
828	685584	567663552	28.7750	9.3902	878	770884	676836152	29.6311	9.5756
829	687241	569722789	28.7924	9.3940	879	772641	679151439	29.6479	9.5792
830	688900	571787000	28.8097	9.3978	880	774400	681472000	29.6648	9.5828
831	690561	573856191	28.8271	9.4016	881	776161	683797841	29.6816	9.5865
832	692224	575930368	28.8444	9.4053	882	777924	686128968	29.6985	9.5901
833	693889	578009537	28.8617	9.4091	883	779689	688465387	29.7153	9.5937
834	695556	580093704	28.8791	9.4129	884	781456	690807104	29.7321	9.5973
835	697225	582182875	28.8964	9.4166	885	783225	693154125	29.7489	9.6010
836	698896	584277056	28.9137	9.4204	886	784996	695506456	29.7658	9.6046
837	700569	586376253	28.9310	9.4241	887	786769	697864103	29.7825	9.6082
838	702244	588480472	28.9482	9.4279	888	788544	700227072	29.7993	9.6118
839	703921	590589719	28.9655	9.4316	889	790321	702595369	29.8161	9.6154
840	705600	592704000	28.9828	9.4354	890	792100	704969000	29.8329	9.6190
841	707281	594823321	29	9.4391	891	793881	707347971	29.8496	9.6226
842	708964	596947688	29.0172	9.4429	892	795664	709732288	29.8664	9.6262
843	710649	599077107	29.0345	9.4466	893	797449	712121957	29.8831	9.6298
844	712336	601211584	29.0517	9.4503	894	799236	714516984	29.8998	9.6334
845	714025	603351125	29.0689	9.4541	895	801025	716917375	29.9166	9.6370
846	715716	605495736	29.0861	9.4578	896	802816	719323136	29.9333	9.6406
847	717409	607645423	29.1033	9.4615	897	804609	721734273	29.9500	9.6442
848	719104	609800192	29.1204	9.4652	898	806404	724150792	29.9666	9.6477
	720801	611960049	29.1376	9.4690	899	808201	726572699	29.9833	9.6513
	722500	614125000	29.1548	9.4727	900	810000	729000000	30	9.6549

TABLE XV.—**Table of squares, cubes, square roots, and cube roots**—Continued.

No.	Square.	Cube.	Sq. rt.	Cu. rt.	No.	Square.	Cube.	Sq. rt.	Cu. rt.
901	811801	731432701	30.0167	9.6585	951	904401	860085351	30.8383	9.8339
902	813604	733870808	30.0333	9.6620	952	906304	862801408	30.8545	9.8374
903	815409	736314327	30.0500	9.6656	953	908209	865523177	30.8707	9.8408
904	817216	738763264	30.0666	9.6692	954	910116	868250664	30.8869	9.8443
905	819025	741217625	30.0832	9.6727	955	912025	870983875	30.9031	9.8477
906	820836	743677416	30.0998	9.6763	956	913936	873722816	30.9192	9.8511
907	822649	746142643	30.1164	9.6799	957	915849	876467493	30.9354	9.8546
908	824464	748613312	30.1330	9.6834	958	917764	879217912	30.9516	9.8580
909	826281	751089429	30.1496	9.6870	959	919681	881974079	30.9677	9.8614
910	828100	753571000	30.1662	9.6905	960	921600	884736000	30.9839	9.8648
911	829921	756058031	30.1828	9.6941	961	923521	887503681	31	9.8683
912	831744	758550528	30.1993	9.6976	962	925444	890277128	31.0161	9.8717
913	833569	761048497	30.2159	9.7012	963	927369	893056347	31.0322	9.8751
914	835396	763551944	30.2324	9.7047	964	929296	895841344	31.0483	9.8785
915	837225	766060875	30.2490	9.7082	965	931225	898632125	31.0644	9.8819
916	839056	768575296	30.2655	9.7118	966	933156	901428696	31.0805	9.8854
917	840889	771095213	30.2820	9.7153	967	935089	904231063	31.0966	9.8888
918	842724	773620632	30.2985	9.7188	968	937024	907039232	31.1127	9.8922
919	844561	776151559	30.3150	9.7224	969	938961	909853209	31.1288	9.8956
920	846400	778688000	30.3315	9.7259	970	940900	912673000	31.1448	9.8990
921	848241	781229961	30.3480	9.7294	971	942841	915498611	31.1609	9.9024
922	850084	783777448	30.3645	9.7329	972	944784	918330048	31.1769	9.9058
923	851929	786330467	30.3809	9.7364	973	946729	921167317	31.1929	9.9092
924	853776	788889024	30.3974	9.7400	974	948676	924010424	31.2090	9.9126
925	855625	791453125	30.4138	9.7435	975	950625	926859375	31.2250	9.9160
926	857476	794022776	30.4302	9.7470	976	952576	929714176	31.2410	9.9194
927	859329	796597983	30.4467	9.7505	977	954529	932574833	31.2570	9.9227
928	861184	799178752	30.4631	9.7540	978	956484	935441352	31.2730	9.9261
929	863041	801765089	30.4795	9.7575	979	958441	938313739	31.2890	9.9295
930	864900	804357000	30.4959	9.7610	980	960400	941192000	31.3050	9.9329
931	866761	806954491	30.5123	9.7645	981	962361	944076141	31.3209	9.9363
932	868624	809557568	30.5287	9.7680	982	964324	946966168	31.3369	9.9396
933	870489	812166237	30.5450	9.7715	983	966289	949862087	31.3528	9.9430
934	872356	814780504	30.5614	9.7750	984	968256	952763904	31.3688	9.9464
935	874225	817400375	30.5778	9.7785	985	970225	955671625	31.3847	9.9497
936	876096	820025856	30.5941	9.7819	986	972196	958585256	31.4006	9.9531
937	877969	822565953	30.6105	9.7854	977	974169	961504803	31.4166	9.9565
938	879844	825293672	30.6268	9.7889	988	976144	964430272	31.4325	9.9598
939	881721	827936019	30.6431	9.7924	989	978121	967361669	31.4484	9.9632
940	883600	830584000	30.6594	9.7959	990	980100	970299000	31.4643	9.9666
941	885481	833237621	30.6757	9.7993	991	982081	973242271	31.4802	9.9699
942	887364	835896888	30.6920	9.8028	992	984064	976191488	31.4960	9.9733
943	889249	838561807	30.7083	9.8063	993	986049	979146657	31.5119	9.9766
944	891136	841232384	30.7246	9.8097	994	988036	982107784	31.5278	9.9800
945	893025	843908625	30.7409	9.8132	995	990025	985074875	31.5436	9.9833
946	894916	846590536	30.7571	9.8167	996	992016	988047936	31.5595	9.9866
947	896809	849278123	30.7734	9.8201	997	994009	991026973	31.5753	9.9900
918	898704	851971392	30.7896	9.8236	998	996004	994011992	31.5911	9.9933
949	900601	854670349	30.8058	9.8270	999	998001	997002999	31.6070	9.9967
950	902500	857375000	30.8221	9.8305	1000	1000000	1000000000	31.6228	10

116. To find the **square root** of a **decimal fraction** or **mixed number** from the foregoing table, multiply by 100 or by 10,000 and find the product in the column of squares. The corresponding number in the first column, with the decimal point one or two places to the left, is the desired root.

For the cube root of a similar number, multiply by 1,000 or by 1,000,000, and find the nearest number in column of cubes. The corresponding number in the first column, with the decimal point one or two places to the left, is the desired root.

Examples: Required the square root of 5.246.

Multiply by 100; the result is 524, which found in column of squares is opposite 23 in the column of numbers. Moving the decimal point one place to the left to correspond with the multiplication by 100, gives 2.3 for the desired square root, to the first place of decimals and hence approximate only. Second: Multiply by 10,000; the result is 52,460, which found in the columns of squares is opposite 229 in the column of numbers. Moving the decimal point two places to the left to correspond to the multiplication by 10,000, the result is 2.29, which is the desired root to the second place of decimals.

Required the cube root of 5.246. Multiply by 1,000, giving 5,246, which found in the column of cubes is opposite the number 17 in the first column. Moving the decimal point one place to the left to correspond to the multiplication by 1,000 gives 1.7, which is the required cube root to one decimal place. Again, multiplying by 1,000,000 gives 5,246,000, which found in the column of cubes is opposite the number 174 in the column of numbers. Moving the decimal point two places to the left to correspond with the multiplication by 1,000,000, gives the number 1.74, which is the desired cube root correct to two places of decimals.

To **find** the **square root** or **cube root** of a **number greater** than 1,000, find the nearest number in the column of squares or cubes and take the corresponding number in the first column, which will be correct for the number of figures it contains.

For the **fourth root,** take the square root of the square root. For the **sixth root,** the square root of the cube root, or the cube root of the square root. **Higher roots,** the indices of which can be factored in 3's and 2's, may be taken in the same way.

117. **Circular functions.**—Those most used are shown graphically in figure 85. They bear a definite relation to the radius of a circle in which they are drawn. When the radius is unity, functions are called **natural,** as nat. sine, nat. tangent, etc. Their values are given in Table XVI for each 10′ of arc. The tabulated values are ratios of the several functions to the radius, and if any length, expressed in any unit, considered as a radius, be multiplied by a tabular number, the result will be the corresponding function of the circle of the given radius. The table gives values from 0 to 90°. For greater angles, use the following relations: Subtract the given angle from 180° or 360°, or subtract 180° from the angle, as may be required, to leave a remainder of 90° or less. Take out the required function of the remainder, which is also that of the given angle.

Interpolation for values not in the table may be done approximately by taking the proportional amount of the difference between two consecutive values. Thus, for the sine of 28° 43′ take the sine of 28° 40′ plus $\frac{3}{10}$ of the difference between sine 28° 40′ and sine 28° 50′.

TABLE XVI.

118. **Natural sines and tangents** to a radius 1:

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
0	00	.0000000	.000000	Infinite.	1.0000000	90	00
	10	.0029089	.002908	343.7737	.9999958		50
	20	.0058177	.005817	171.8854	.9999831		40
	30	.0087265	.008726	114.5886	.9999619		30
	40	.0116353	.011636	85.93979	.9999323		20
	50	.0145439	.014545	68.75008	.9998942		10
1	00	.0174524	.017455	57.28996	.9998477	89	00
	10	.0203608	.020365	49.10388	.9997927		50
	20	.0232690	.023275	42.96407	.9997292		40
	30	.0261769	.026185	38.18845	.9996573		30
	40	.0290847	.029097	34.36777	.9995770		20
	50	.0319922	.032008	31.24157	.9994881		10
2	00	.0348995	.034920	28.63625	.9993908	88	00
	10	.0378065	.037833	26.43160	.9992851		50
	20	.0407131	.040746	24.54175	.9991709		40
	30	.0436194	.043660	22.90376	.9990482		30
	40	.0465253	.046575	21.47040	.9989171		20
	50	.0494308	.049491	20.20555	.9987775		10
3	00	.0523360	.052407	19.08113	.9986295	87	00
	10	.0552406	.055325	18.07497	.9984731		50
	20	.0581448	.058243	17.16933	.9983082		40
	30	.0610485	.061162	16.34985	.9981348		30
	40	.0639517	.064082	15.60478	.9979530		20
	50	.0668544	.067004	14.92441	.9977627		10
4	00	.0697565	.069926	14.30066	.9975641	86	00
	10	.0726580	.072850	13.72673	.9973569		50
	20	.0755589	.075775	13.19688	.9971413		40
	30	.0784591	.078701	12.70620	.9969173		30
	40	.0813587	.081629	12.25050	.9966849		20
	50	.0842576	.084558	11.82616	.9964440		10
5	00	.0871557	.087488	11.43005	.9961947	85	00
	10	.0900532	.090420	11.05943	.9959370		50
	20	.0929499	.093354	10.71191	.9956708		40
	30	.0958458	.096289	10.38539	.9953962		30
	40	.0987408	.099225	10.07803	.9951132		20
	50	.1016351	.102164	9.788173	.9948217		10
6	00	.1045285	.105104	9.514364	.9945219	84	00
	10	.1074210	.108046	9.255303	.9942136		50
	20	.1103126	.110989	9.009826	.9938969		40
	30	.1132032	.113935	8.776887	.9935719		30
	40	.1160929	.116883	8.555546	.9932384		20
	50	.1189816	.119832	8.344955	.9928965		10
7	00	.1218693	.122784	8.144346	.9925462	83	00
	10	.1247560	.125738	7.953022	.9921874		50
	20	.1276416	.128694	7.770350	.9918204		40
	30	.1305262	.131652	7.595754	.9914449		30
	40	.1334096	.134612	7.428706	.9910610		20
	50	.1362919	.137575	7.268725	.9906687		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

TABLE XVI.—**Natural Sines and Tangents**—Continued.

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
8	00	.1391731	.140540	7.115369	.9902681	82	00
	10	.1420531	.143508	6.968233	.9938590		50
	20	.1449319	.146478	6.826943	.9894416		40
	30	.1478094	.149451	6.691156	.9890159		30
	40	.1506857	.152426	6.560453	.9885817		20
	50	.1535607	.155404	6.434842	.9881392		10
9	00	.1564345	.158384	6.313751	.9876883	81	00
	10	.1593069	.161367	6.197027	.9872291		50
	20	.1621779	.164353	6.084438	.9867615		40
	30	.1650476	.167342	5.975764	.9862856		30
	40	.1679159	.170334	5.870804	.9858013		20
	50	.1707828	.173329	5.769368	.9853087		10
10	00	.1736482	.176327	5.671281	.9848078	80	00
	10	.1765121	.179327	5.576378	.9842985		50
	20	.1793746	.182331	5.484505	.9838808		40
	30	.1822355	.185339	5.395517	.9832549		30
	40	.1850949	.188349	5.309279	.9827206		20
	50	.1879528	.191363	5.225664	.9821781		10
11	00	.1908090	.194380	5.144554	.9816272	79	00
	10	.1936636	.197400	5.065835	.9810680		50
	20	.1965166	.200424	4.989402	.9805005		40
	30	.1993679	.203452	4.915157	.9799247		30
	40	.2022176	.206483	4.843004	.9793406		20
	50	.2050655	.209518	4 772856	.9787483		10
12	00	.2079117	.212556	4.704630	.9781476	78	00
	10	.2107561	.215598	4.638245	.9775386		50
	20	.2135988	.218644	4.573628	.9762215		40
	30	.2164396	.221694	4.510708	.9762960		30
	40	.2192786	.224748	4.449418	.9756623		20
	50	.2221158	.227806	4.389694	.9750203		10
13	0	.2249511	.230868	4.331475	.9743701	77	00
	10	.2277844	.233934	4.274706	.9737116		50
	20	.2306159	.237004	4.219331	.9730449		40
	30	.2334454	.240078	4.165299	.9723699		30
	40	.2362729	.243157	4.112561	.9716867		20
	50	.2390984	.246240	4.061070	.9709953		10
14	00	.2419219	.249328	4.010780	.9702957	76	00
	10	.2447433	.252420	3.961651	.9695879		50
	20	.2475627	.255516	3.913642	.9688719		40
	30	.2503800	.258617	3.866713	.9681476		30
	40	.2531952	.261723	3.820828	.9674152		20
	50	.2560082	.264833	3.775951	.9666746		10
15	00	.2588190	.267949	3.732050	.9659258	75	00
	10	.2616277	.271069	3.689092	.9651681		50
	20	.2644342	.274194	3.647046	.9644037		40
	30	.2672384	.277324	3.605883	.9636305		30
	40	.2700403	.280459	3.565574	.9628490		20
	50	.2728400	.283599	3.526093	.9620594		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

TABLE XVI.—**Natural Sines and Tangents**—Continued.

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
16	00	.2756374	.286745	3.487414	.9612617	74	00
	10	.2784324	.289896	3.449512	.9604558		50
	20	.2812251	.293052	3.412362	.9596118		40
	30	.2840153	.296213	3.375943	.9588197		30
	40	.2868032	.299380	3.340232	.9579895		20
	50	.2895887	.302552	3.305209	.9571512		10
17	00	.2923717	.305730	3.270852	.9563048	73	00
	10	.2951522	.308914	3.237143	.9554502		50
	20	.2979303	.312103	3.204063	.9545876		49
	30	.3007058	.315298	3.171594	.9537170		30
	40	.3034788	.318499	3.139719	.9528382		20
	50	.3062492	321706	3.108421	.9519514		10
18	00	.3090170	.324919	3.077683	.9510565	72	00
	10	.3117822	.328138	3.047491	.9501536		50
	20	.3145448	.331363	3.017830	.9492426		40
	30	.3173047	.334595	2.988685	.9483237		30
	40	.3200619	.337833	2.960042	.9473966		20
	50	.3228164	.341077	2.931888	.9464616		10
19	00	.3255682	.344327	2.904210	.9455186	71	00
	10	.3283172	.347584	2.876997	.9445675		50
	20	.3310634	.350848	2.850234	.9436085		40
	30	.3338069	.354118	2.823912	.9426415		30
	40	.3365475	.357395	2.798019	.9416665		20
	50	.3392852	.360679	2.772544	.9406835		10
20	00	.3420201	.363970	2.747477	.9396926	70	00
	10	.3447521	.367268	2.722807	.9386938		50
	20	.3474812	.370572	2.698525	.9376869		40
	30	.3502074	.373884	2.674621	.9366722		30
	40	.3529306	.377203	2.651086	.9356495		20
	50	.3556508	.380530	2.627912	.9346189		10
21	00	.3583679	.383864	2.605089	.9335804	69	00
	10	.3610821	.387205	2.582609	.9325340		50
	20	.3637932	.390554	2.560464	.9314797		40
	30	.3665012	.393910	2.538647	.9304176		30
	40	.3692061	.397274	2.517150	.9293475		20
	50	.3710079	.400646	2.495966	.9282696		10
22	00	.3746066	.404026	2.475086	.9271839	68	00
	10	.3773021	.407413	2.454506	.9260902		50
	20	.3799944	.410809	2.434217	.9249888		40
	30	.3826834	.414213	2.414213	.9238795		30
	40	.3853693	.417625	2.394488	.9227624		20
	50	.3880518	.421046	2.375037	.9216375		10
23	00	.3907311	.424474	2.355852	.9205049	67	00
	10	.3934071	.427912	2.336928	.9193644		50
	20	.3960798	.431357	2.318260	.9182161		40
	30	.3987491	.434812	2.299842	.9170601		30
	40	.4014150	.438275	2.281669	.9158963		20
	50	.4040775	.441747	2.263735	.9147247		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

TABLE XVI.—**Natural Sines and Tangents**—Continued.

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
24	00	.4067366	.445228	2.246036	.9135455	66	00
	10	.4093923	.448718	2.228567	.9123584		50
	20	.4120445	.452217	2.211323	.9111637		40
	30	.4146932	.455726	2.194299	.9099613		30
	40	.4173385	.459243	2.177492	.9087511		20
	50	.4199801	.462771	2.160895	.9075333		10
25	00	.4226183	.466307	2.144506	.9063078	65	00
	10	.4252528	.469853	2.128321	.9050746		50
	20	.4278838	.473409	2.112334	.9038338		40
	30	.4305111	.476975	2.096543	.9025853		30
	40	.4331348	.480551	2.080943	.9013292		20
	50	.4357548	.484136	2.065531	.9000654		10
26	00	.4383711	.487732	2.050303	.8987940	64	00
	10	.4409838	.491338	2.035256	.8975151		50
	20	.4435927	.494954	2.020386	.8962285		40
	30	.4461978	.498581	2.005689	.8949344		30
	40	.4487992	.502218	1.991163	.8936326		20
	50	.4513967	.505866	1.976805	.8923234		10
27	00	.4539905	.509525	1.962610	.8910065	63	00
	10	.4565804	.513195	1.948577	.8896822		50
	20	.4591665	.516875	1.934702	.8883503		40
	30	.4617486	.520567	1.920982	.8870108		30
	40	.4643269	.524269	1.907414	.8856639		20
	50	.4669012	.527983	1.893997	.8843095		10
28	00	.4694716	.531709	1,880726	.8829476	62	00
	10	.4720380	.535446	1.867600	.8815782		50
	20	.4746004	.539195	1.854615	.8802014		40
	30	.4771588	.542955	1.841770	.8788171		30
	40	.4797131	.546728	1.829062	.8774254		20
	50	.4822634	.550512	1.816489	.8760263		10
29	00	.4848096	.554309	1.804047	.8746197	61	00
	10	.4873517	.558117	1.791736	.8732058		50
	20	.4898897	.561939	1.779552	.8717844		40
	30	.4924236	.565772	1.767494	.8703557		30
	40	.4949532	.569619	1.755559	.8689196		20
	50	.4974787	.573478	1.743745	.8674762		10
30	00	.5000000	.577350	1.732050	.8660254	60	00
	10	.5025170	.581235	1.720473	.8645673		50
	20	.5050298	.585133	1.709011	.8631019		40
	30	.5075384	.589045	1.697663	.8616292		30
	40	.5100426	.592969	1.686426	.8601491		20
	50	.5125425	.596908	1.675298	.8586619		10
31	00	.5150381	.600860	1.664279	.8571673	59	00
	10	.5175293	.604826	1.653366	.8556655		50
	20	.5200161	.608806	1.642557	.8541504		40
	30	.5224986	.612800	1.631851	.8526402		30
	40	.5249766	.616809	1.621246	.8511167		20
	50	.5274502	.620832	1.610741	.8495860		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

TABLE XVI.—**Natural Sines and Tangents**—Continued.

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	'					°	'
32	00	.5299193	.624869	1.600334	.8480481	58	00
	10	.5323839	.628921	1.590023	.8465030		50
	20	.5348440	.632988	1.579807	.8449508		40
	30	.5372996	.637070	1.569685	.8433914		30
	40	.5397507	.641167	1.559655	.8418249		20
	50	.5421971	.645279	1.549715	.8402513		10
33	00	.5446390	.649407	1.539865	.8386706	77	00
	10	.5470763	.653551	1.530102	.8370827		50
	20	.5495090	.657710	1.520426	.8354878		40
	30	.5519370	.661885	1.510835	.8338858		30
	40	.5543603	.666076	1.501328	.8322768		20
	50	.5567790	.670284	1.491903	.8306607		10
34	00	.5591929	.674508	1.482561	.8290376	56	00
	10	.5616021	.678749	1.473298	.8274074		50
	20	.5640066	.683006	1.464114	.8257703		40
	30	.5664062	.687281	1.455009	.8241262		30
	40	.5688011	.691572	1.445980	.8224751		20
	50	.5711912	.695881	1.437026	.8208170		10
35	00	.5735764	.700207	1.428148	.8191520	55	00
	10	.5759568	.704551	1.419342	.8174801		50
	20	.5783323	.708913	1.410609	.8158013		40
	30	.5807030	.713293	1.401948	.8141155		30
	40	.5830687	.717691	1.393357	.8124229		20
	50	.5854294	.722107	1.384835	.8107234		10
36	00	.5877853	.726542	1.376381	.8090170	54	00
	10	.5901361	.730996	1.367995	.8073038		50
	20	.5924819	.735469	1.359676	.8055837		40
	30	.5948228	.739961	1.351422	.8038569		30
	40	.5971586	.744472	1.343233	.8021232		20
	50	.5994893	.749003	1.335107	.8003827		10
37	00	.6018150	.753554	1.327044	.7986355	53	00
	10	.6041356	.758124	1.319044	.7968815		50
	20	.6064511	.762715	1.311104	.7951208		40
	30	.6087614	.767327	1.303225	.7933533		30
	40	.6110666	.771958	1.295405	.7915792		20
	50	.6133666	.776611	1.287644	.7897983		10
38	00	.6156615	.781285	1.279941	.7880108	52	00
	10	.6179511	.785980	1.272295	.7862165		50
	20	.6202355	.790697	1.264706	.7844157		40
	30	.6225146	.795435	1.257172	.7826082		30
	40	.6247885	.800196	1.249693	.7807940		20
	50	.6270571	.804979	1.242268	.7789733		10
39	00	.6293204	.809784	1.234897	.7771460	51	00
	10	.6315784	.814611	1.227578	.7753121		50
	20	.6338310	.819462	1.220312	.7734716		40
	30	.6360782	.824336	1.213097	.7716246		30
	40	.6383201	.829233	1.205932	.7697710		20
	50	.6405566	.834154	1.198818	.7679110		10
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

TABLE XVI.—**Natural Sines and Tangents**—Continued.

Arc.		Sine.	Tang.	Cotang.	Cosine.		
°	′					°	′
40	00	.6427876	.839099	1.191753	.7660444	50	00
	10	.6450132	.844068	1.184737	.7641714		50
	20	.6472334	.849062	1.177769	.7622919		40
	30	.6494480	.854080	1.170849	.7604060		30
	40	.6516572	.859124	1.163976	.7585136		20
	50	.6538609	.864192	1.157149	.7566148		10
41	00	.6560590	.869286	1.150368	.7547096	49	00
	10	.6582516	.874406	1.143632	.7527980		50
	20	.6604386	.879552	1.136941	.7508800		40
	30	.6626200	.884725	1.130294	.7489557		30
	40	.6647959	.889924	1.123690	.7470251		20
	50	.6669661	.895150	1.117130	.7450881		10
42	00	.6691306	.900404	1.110612	.7431448	48	00
	10	.6712895	.905685	1.104136	.7411953		50
	20	.6734427	.910994	1.097702	.7392394		40
	30	.6755902	.916331	1.091308	.7372773		30
	40	.6777320	.921696	1.084955	.7353090		20
	50	.6798681	.927091	1.078642	.7333345		10
43	00	.6819984	.932515	1.072368	.7313537	47	00
	10	.6841229	.937968	1.066134	.7293668		50
	20	.6862416	.943451	1.059938	.7273736		40
	30	.6883546	.948964	1.053780	.7253744		30
	40	.6904617	.954508	1.047659	.7233690		20
	50	.6925630	.960082	1.041576	.7213574		10
44	00	.6946584	.965688	1.035530	.7193398	46	00
	10	.6967479	.971326	1.029520	.7173161		50
	20	.6988315	.976995	1.023546	.7152863		40
	30	.7009093	.982697	1.017607	.7132504		30
	40	.7029811	.988431	1.011703	.7112086		20
	50	.7050469	.994199	1.005834	.7091607		10
45	00	.7071068	1.000000	1.000000	.7071068	45	00
		Cosine.	Cotang.	Tang.	Sine.	Arc.	

119. **Properties of circles.**—The ratio of the diameter to the circumference is represented in mathematics by π called **Pi.** Its value can not be exactly expressed. To 5 decimal places it is 3.14159, which equals π nearly. Log. π equals 0.4971499.

Diam. × 3.14159 = circ.
Diam. × 0.886277 = side of square of equal area.
Diam. × 0.7071 = side of inscribed square.
$\frac{1}{4}\pi D^2 = 0.7854 \times D^2$ = Area of the circle.
$\pi r^2 = 3.1416 \times r^2$ = Area of the circle.
The length of an arc of $n°$ = $rn \times 0.017453$.

Example: If the radius is 542 ft., the length of an arc of 18° 20′ = 18°.33 × 542 × 0.017453 = 165.5 ft.

120. **Properties of some plane figures.**—Triangles are classed as equilateral when the 3 sides are of equal length; isoceles, when two sides only are equal; acute-angled, when each of its angles is less than 90°; obtuse-angled, when one angle is greater than 90°.

The sum of the angles of any triangle is 180°. The sides are directly proportional to the sines of the opposite angles, the greatest and least sides opposite the greatest and least angles.

Formulas for the solution of plane triangles. (Fig. 86.)

Given 2 sides, as *a* and *b*, and an angle opposite to one of them, as *B*.

$$\text{Sin. } A=\frac{a \sin. B}{b};\ C=180^\circ-(A+B);\ c=\frac{a \sin. C}{\sin. A}.$$

Given 2 angles as *A* and *B* and the included side *c*, the most common case.

$$C=180^\circ-(A+B);\ a=\frac{c \sin. A}{\sin. C};\ b=\frac{a \sin. B}{\sin. A}.$$

Given 2 sides at *a* and *b*, and the included angle *C*.

$$180^\circ-C=A+B$$

$$\text{Tan.}\frac{A-B}{2}=\frac{(a-b)\frac{(A+B)}{2}}{a+b}$$

$$A=\frac{A+B}{2}+\frac{A-B}{2};\ B=\frac{A+B}{2}-\frac{A-B}{2};\ C=\frac{a \sin. C}{\sin. A}.$$

Given the 3 sides—

$$\frac{a+b+c}{2}=S;\ \sin.\frac{A}{2}=\sqrt{\frac{(S-b)\ (S-c)}{bc}};$$

$$\sin.\frac{B}{2}=\sqrt{\frac{(S-a)\ (S-c)}{ac}};\ \sin.\frac{C}{2}=\sqrt{\frac{(S-a)\ (S-b)}{ab}}.$$

For every **right-angled** triangle the sine of the right angle is 1 and the following relations result: The side opposite the right angle is called the **hypothenuse** (fig. 86).

$\text{Hypothenuse}=a=c\div\sin. C=c\times\sec. B=\frac{b}{\text{Cos. } C}$

$=b\times\sec. C=\sqrt{b^2+c^2};$

$b=a\times\sin. B=a\times\cos. C=c\times\text{cotang. } C=c\times\text{tang. } B;$

$c=a\times\sin. C=a\times\cos. B=b\times\text{tang. } C;$

$\sin. B=\frac{b}{a}\cos. C;\ \sin. C=\frac{c}{a}=\cos. B;$

$\text{tang. } B=\frac{b}{c}=\text{cotang. } C;\ \text{tang. } C=\frac{c}{b}=\text{cotang. } B.$

The area of a triangle equals any side multiplied by one-half the perpendicular distance from that side to the opposite angle. If the perpendicular from the angle does not intersect the opposite side, prolong the side but do not include the prolongation in its length for computing the area. All triangles which have a common side and their opposite angles in a straight line parallel to the common side are equal in area.

A line bisecting one angle divides the opposite side into parts proportional to the adjacent sides. In figure 87 *ab* bisects the angle at *a* and *bc: ac::bd:ad.*

Lines drawn from each angle to the middle of the opposite side intersect in a common point which is the center of gravity of the triangle. The shorter part of each line is one-half the longer (fig. 88).

A line joining the middle points of two sides is parallel to the third side and one-half its length. In figure 88 the line *ef*, joining the middle points of *ab* and *bc*, is parallel to *ac* and one-half its length. Lines joining *eg* and *fg* would be parallel to *ab* and *bc* and half their length, respectively.

Similar triangles are those which have the same angles and differ only in length of sides. The ratio between corresponding sides of all similar triangles is the same, since it is the ratio of the same function of the same angles. Hence, if two sides of a triangle and one of the corresponding sides of a similar triangle are known the other corresponding side may be determined. The simplest test of similar triangles is that their corresponding sides are parallel or perpendicular. The principle of similar triangles is of great utility in field geometry.

The side of a square equals the diameter of an inscribed circle; or the diameter of a circumscribed circle × 0.7071. The diagonal of a square equals one side × 1.4142.

The area of a trapezoid (fig. 89) equals one-half the sum of the parallel sides *ab* and *cd* multiplied by the distance between them, *ef*.

The area of a trapezium—no two sides parallel—(fig. 90) equals one-half the diagonal *ac* multiplied by the sum of the perpendiculars, *bf* and *de*.

The side of a hexagon equals the radius of a circumscribed circle. The area equals the square of one side × 2.598. The side of an octagon equals the radius of a circumscribed circle × 0.7633. The area equals the square of one side × 4.8289.

To draw an octagon in a square (fig. 91).—From each corner with a radius equal to one-half the diagonal describe arcs as shown. Join the points at which they cut the sides. If a square stick be scribed at a distance from each corner equal to 0.3 the side of the square and the corners chamfered to the marks the resulting section will be nearly a true octagon.

121. **Geometrical constructions.**—To divide a straight line into any number of equal parts. From one end of the line draw another, making any convenient angle with it, as 10° or 20°. On this auxiliary line lay off any assumed distance as many times as the number of equal parts desired. Join the last point so determined with the end of the first line. Through each of the points marked on the auxiliary line draw a line parallel to the line joining the ends. These lines will divide the given line into the desired number of equal parts.

To draw a perpendicular from a given point on a line: Mark two points equidistant from the given point (fig. 92) and with them as centers and a radius greater than their distance from the given point describe arcs on each side of the line. Connect one intersection with the given point by a straight line, which is the perpendicular required. As a check on accuracy, note whether the line passes through the other intersection.

If the given point is at one end of the line, from a convenient point *c* outside the line describe a semicircle passing through the given point and cutting the line again as at *b* (fig. 95). Draw a straight line *bc* through the center to the arc on the other side as at *d*. The line *da* is the perpendicular required.

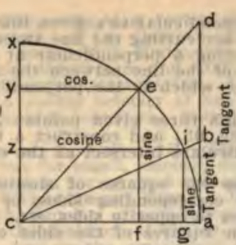


Fig. 85

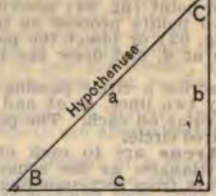


Fig. 86

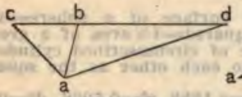


Fig. 87

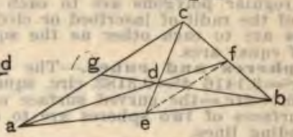


Fig. 88

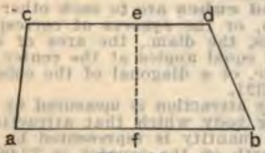


Fig. 89

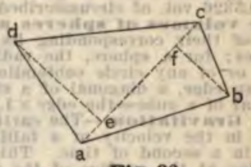


Fig. 90

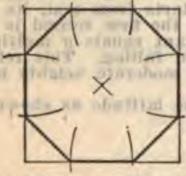


Fig. 91

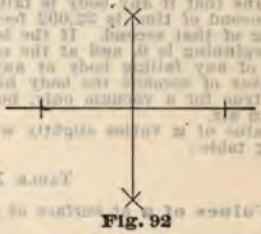


Fig. 92

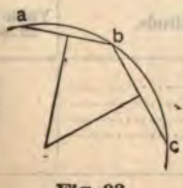


Fig. 93

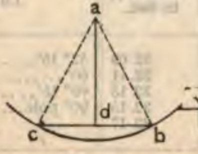


Fig. 94

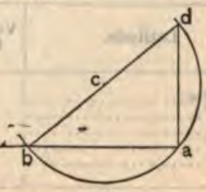


Fig. 95

From a given point to let fall a perpendicular to a given line. From the given point (fig. 94) describe an arc cutting the line twice. With these two points proceed as in erecting a perpendicular at a given point (fig. 92) or bisect the portion of the line between the intersections, as at *d*, and draw the line *ad*, which is the perpendicular required.

To describe a circle passing through three given points: Join the points by two lines, as *ab* and *bc* (fig. 93) and construct a bisecting perpendicular on each. The perpendiculars intersect at the center of the required circle.

122. **Areas** are to each other as the squares of similar lines; similar triangles as the squares of corresponding sides, or of perpendiculars from corresponding angles to opposite sides, etc.

Squares are to each other as the squares of the sides or diagonals.

Other regular polygons are to each other as the squares of the sides or of the radii of inscribed or circumscribed circles.

Circles are to each other as the squares of diams., or radii, or chords of equal arcs.

123. **Spheres and cubes.**—The surface of a sphere$=4\pi r^2=12.5664\ r^2=3.1416\ d^2=0.3183$ circ. squared$=4\times$area of a great circle$=$diam.$\times$circ.$=$the curved surface of circumscribed cylinder.

The surfaces of two spheres are to each other as the squares of corresponding lines.

The volume of a sphere$=\frac{4}{3}\pi\ r^3=4.1888\ r^3=0.5236\ d^3=0.01689$ circ.$^3=\frac{2}{3}$ diam.$\times$area of great circle$=\frac{2}{3}$ vol. of circumscribed cylinder$=0.5326$ vol. of circumscribed cube.

The volumes of spheres and cubes are to each other as the *cubes* of their corresponding *lines*, or the *squares* of corresponding *surfaces;* for a sphere, the radius, the diam., the area of a great circle, or of any circle subtending equal angles at the center; for a cube, an edge, a diagonal of a side, or a diagonal of the cube. The diagonal of a cube$=$the edge$\times 1.7321$.

124. **Gravitation.**—The earth's attraction is measured by the increase in the velocity of a falling body which that attraction produces in a second of time. This quantity is represented by *g*, and its value at the surface of the earth on the equator is 32.092 feet. This means that if any body is falling freely its velocity at the end of any second of time is 32.092 feet per second greater than at the beginning of that second. If the body starts from rest, its velocity at the beginning is 0, and at the end of the first second is *g*. The velocity of any falling body at any instant equals *g* multiplied by the number of seconds the body has been falling. This relation is strictly true for a vacuum only, but for moderate heights is nearly correct in air.

The value of **g** varies slightly with the latitude as shown in the following table:

TABLE XVII.

125. **Values of g** at surface of earth in different latitudes:

Latitude.	Value of *g*, in feet.	Latitude.	Value of *g*, in feet.
Equator	32.09	52° 15′	32.19
20° 40′	32.11	60°	32.21
30°	32.13	69° 15′	32.23
37° 10′	32.15	90° pole	32.25
45°	32.17		

126. The value of g varies also with the distance from the center of the earth; or the distance above or below the surface, diminishing in both cases. This diminution is approximately 0.016 feet for each mile above the surface and 0.008 feet for each mile below.

127. The fundamental law of motion of falling bodies is $v^2=2gh$, in which v=the velocity at any point in feet per second; h, the distance through which the body has fallen from rest to the given instant.

As $v=gt$, $h=\frac{1}{2}gt^2=16t^2$. These relations are strictly true only in vacuo, but for small, smooth, dense objects are approximately correct for motion in air up to 5 seconds.

128. Centrifugal force.—If w=the weight of a revolving body and n the number of revolutions per minute, r=the radius of revolution or the distance of center of gravity of the body from center of motion, and c=the centrifugal force or pull on the radius in pounds, then $c=0.00034wrn^2$.

PART II.

BRIDGES.

PART II—BRIDGES.

1. The **kind of bridge** to be built depends upon the *load*, the nature of the *obstacle*, and the *materials* available. Time is of prime importance in the construction of bridges for troops in campaign and the proper distribution of men and material to do the work quickly must be made.

2. **Loads.**—Loads are classified as *dead* or stationary and *live* or moving. Generally speaking, the former is the weight of the bridge itself and the latter the weight of the traffic over it. Loads are usually stated in pounds per square foot for highway and per linear foot for military and railway bridges. Some loads of military bridges are as follows, all in pounds per linear foot: Infantry, single file, 140; infantry, column of twos, 280; infantry, column of fours, 560; cavalry in single file, 196; cavalry in columns of twos, 392. Infantry in heavy marching order average 200 pounds per man; when unarmed, 160 pounds. When crowded in a mass they may weigh 133 pounds per square foot of standing room.

TABLE I.

3. Weights of guns and military carriages, fully loaded for traveling:

	Weight on the wheels.		Distance between axles, c. to c.	Width of wheel track, c. to c.		Width of tires.		Length over all.	Width of shoes.
	Front.	Hind.		Front.	Rear.	Front.	Rear.		
	Lbs.	*Lbs.*	*Ft. Ins.*	*Ft. Ins.*	*Ft. Ins.*	*Ins.*	*Ins.*	*Ft. Ins.*	*Ins.*
3.2-inch B. L. F. gun	1,735	2,970	8 7	5					
3.6-inch B. L. F. gun	1,870	2,415	8 9	5					
3.2-inch caisson	1,775	2,805	8 5¾	5					
3.6-inch caisson	1,930	3,070	8 6	5					
Battery and forge wagon	1,130	2,130	8 6	5					
5-inch siege rifle	2,530	6,425	8 1¼	5					
7-inch siege howitzer	2,510	6,920	8 1¼	5					
Maxim automatic	1,950	1,230	7 0	5					
Gatling	754	1,075	7 0	5					
Army escort wagon (4 mules)	2,500	2,500	5 9½	5					
Army wagon (6 mules)	3,500	3,500	6 1½	5					
3-inch gun	1,855	2,405	11 5	5 0		3			
3-inch caisson (loaded)	1,855	2,705	9 0	5 0		3			
4.7-inch gun	[1] 2,645	[1] 6,138	11 1	5 0		5			8½
6-inch howitzer	[1] 3,000	[1] 6,500	12 0	5 0		5			8½
7.6-inch howitzer	[1] 920	[1] 8,460	15 4	5 0		5			8½
9.5-inch howitzer	[1] 3,500	[1] 13,500	15 0	6 3		7			11
12-inch howitzer	[1] 18,600	[1] 5,300	18 0	7 4		8			12
1½-ton motor truck (Packard)			12 0	4 8	5 3	3½	9	17 10	
Unloaded	2,635	3,285							
Loaded	2,935	5,985							
3-ton motor truck (Peerless)			12 7	5 8	6 0	5	11	18 11	
Unloaded	3,300	6,175							
Loaded	4,034	10,441							

TABLE 1.—Weights of guns and military carriages, etc.—Continued.

	Weight on the wheels.		Distance between axles, c. to c.	Width of wheel track, c. to c.		Width of tires.		Length over all.	Width of shoes.
	Front.	Hind.		Front.	Rear.	Front.	Rear.		
	Lbs.	*Lbs.*	*Ft. Ins.*	*Ft. Ins.*	*Ft. Ins.*	*Ins.*	*Ins.*	*Ft. Ins.*	*Ins.*
The maximum and minimum weights of motor trucks on the approved list (April, 1917) in the office of the Quartermaster General is as follows:									
1½-ton motor truck—									
Maximum—									
Unloaded	2,700	5,400							
Loaded	3,300	7,800							
Minimum—									
Unloaded	2,275	2,750							
Loaded	2,875	5,150							
3-ton motor truck—									
Maximum—									
Unloaded	4,500	5,800							
Loaded	5,700	10,600							
Minimum—									
Unloaded	3,470	5,005							
Loaded	4,034	10,441							

---

[1] Weight exclusive of shoes.

The weight to be added to the above figures, if two wheels are equipped with shoes, ranges from 900 pounds for the 4.7-inch gun to 3,000 pounds for the 12-inch howitzer.

The 45-horsepower caterpillar tractor tentatively adopted for traction of the 4.7-inch, 6-inch, 7.6-inch, and 9.5-inch guns and howitzers weighs about 16,000 pounds, is 13 feet long over all, has two tracks each 13 inches wide and 6 feet 8 inches in length of bearing surface, the tracks being 5 feet 1½ inches center to center. If later found necessary, tracks of width up to 30 inches may be provided.

The 75-horsepower caterpillar tractor for the 12-inch howitzer weighs about 25,000 pounds.

4. **Bridges for general road traffic.**—The *dead load* is the weight of the superstructure. Estimate quantities of the different materials and multiply by unit weights from the tables following.

The *live load* is *assumed* at 100 pounds per square foot of floor, or 5 tons concentrated on two axles 5 feet long and 8 feet center to center.

Bridges for a special purpose exclusively may be proportioned for the corresponding load.

5. **Railroad bridges.**—The *dead load* is computed as before. To save time the floor, consisting of rails, ties, and guard timbers only, may be taken at 400 pounds per linear foot of **track.**

The *live load* on *each* track, supposed to be moving in either direction, may be assumed at 6,000 pounds per linear foot of track, or 50,000 pounds on each of two pairs of driving wheels 7½ feet center to center.

6. **Site.**—Favorable conditions are narrowness of stream; stable banks of equal height; hard but penetrable bottom; moderate depth and current; permanent water level; and absence of navigation.

7. **Measurement of width** will be done directly by use of tape, wire, or line, if practicable. Boats or floats may be used to support a long line. Otherwise, by intersections (see Topographical reconnaissance).

8. **Strength of wooden beams.**—For crushing, tensile, and shearing strength, multiply the cross section in square inches by the unit stresses in Table II. The result will be the ultimate tensile strength in pounds. This divided by the adopted factor of safety gives the safe tensile load in pounds. From this the crushing and shearing strengths are derived by applying the percentages given in the table.

For *transverse strength.*—Multiply breadth of cross section by square of depth; divide by three-fourths of the length between supports, all in inches; multiply by factor in column 2, Table II. The result will be the *breaking* load in pounds applied uniformly, or *twice* the breaking load applied at *center* of span. The *safe* load is one-fourth to one-sixth of the above, depending upon the importance of the structure, its temporary or permanent character, and the amount of vibration probably caused by the live load. The ratio of breaking load to maximum actual load is the *factor* of *safety.* It should be 4 to 6 as above.

The *breadth* of a rectangular cross section is the face to which a load is applied. The *depth* is the face at right angles to the breadth.

A round beam has six-tenths the transverse strength of a square beam with breadth and depth equal to its middle diameter.

TABLE III.

14. **Safe loads** in pounds for **long-leaf pine beams, uniformly loaded,** and 1 inch in width; factor of safety 5; being values of *C* in Formula (B); authority, United States Department of Agriculture:

Length of beam.	Depth of beam in inches (width equals 1 inch).								
	4	5	6	8	10	12	14	16	18
Feet.									
4	689	1,076	1,550	....	....	....	....	....	....
5	551	861	1,240	....	....	....	....	....	....
6	459	718	1,033	1,837	....	....	....	....	....
7	394	615	885	1,574	2,460	....	....	....	....
8	344	538	775	1,376	2,150	3,100	....	....	....
9	306	478	688	1,224	1,914	2,755	....	....	....
10	276	431	620	1,101	1,720	2,480	3,370	....	....
11	251	391	562	1,000	1,564	2,253	3,068	4,010	....
12	230	359	517	917	1,434	2,067	2,812	3,673	4,650
13	212	331	477	847	1,322	1,906	2,595	3,390	4,285
14	197	308	442	787	1,230	1,770	2,408	3,145	3,980
15	184	287	413	733	1,147	1,653	2,250	2,940	3,720
16	172	269	386	688	1,074	1,550	2,109	2,753	3,485
17	162	253	364	647	1,013	1,459	1,984	2,590	3,280
18	153	239	343	612	956	1,379	1,878	2,450	3,100
19	145	227	327	580	905	1,305	1,777	2,320	2,933
20	138	215	310	550	860	1,240	1,689	2,206	2,790
21	131	205	296	525	820	1,181	1,609	2,100	2,656
22	126	196	281	500	783	1,129	1,536	2,005	2,535

15. The effect of seasoning is to increase the strength of timber. Green timber has about 20 per cent less strength than that shown in the usual tables, and the factor of safety may be increased accordingly. Table III, used for green timber, gives the factor of safety 4 instead of 5, which will usually be sufficient.

TABLE IV.

16. **Working load** in pounds of **pillars** of half-seasoned white or common yellow pine, firmly fixed and equally loaded; based on formula of C. Shaler Smith, C. E., with f. s. of 5:

Length.	Side of square pillar in inches.							
	3	4	5	6	7	8	10	12
Feet.								
5	3,461	8,419	15,865	25,711	37,867	52,237	87,420	130,896
6	2,903	6,970	13,670	22,846	34,437	48,333	82,860	125,885
7	2,176	5,789	11,740	20,182	31,095	44,403	78,000	120,413
8	1,766	4,838	10,100	17,784	27,969	40,614	73,040	114,653
9	1,456	4,083	8,725	15,682	25,108	37,018	68,180	108,749
10	1,217	3,478	7,565	13,846	22,520	33,677	63,460	102,845
12	880	2,589	5,845	10,894	18,336	27,878	54,680	91,382
14	664	1,987	4,530	8,705	15,387	23,155	46,960	80,720
16	518	1,565	3,625	7,063	12,221	19,366	40,400	71,136
18	425	1,264	2,945	5,825	10,182	16,333	34,900	62,726
20	372	1,034	2,445	4,867	8,560	13,914	30,260	55,382
22	....	867	2,060	4,118	7,311	11,982	26,400	49,046
24	....	736	1,750	3,521	6,361	10,355	23,380	43,574
26	....	630	1,510	3,046	5,390	8,960	20,440	38,880
28	....	....	1,310	2,647	4,596	7,949	18,120	34,819
30	....	....	1,150	2,340	4,224	7,040	16,180	31,306
32	....	....	1,015	2,074	3,753	6,259	14,500	28,253
34	....	....	905	1,850	3,391	5,619	13,060	25,603
36	....	....	....	1,656	3,009	5,094	11,620	23,270
38	....	....	....	1,490	2,725	4,582	10,740	21,254
40	....	....	....	1,354	2,470	4,160	9,780	19,469

When a wooden beam is to bear compression in the direction of the fibers, no matter whether vertical, horizontal, or inclined, its safe load is that given in this table.

The *factor of safety* of timber against *crushing* should be 6 to 8 for important structures and 4 to 6 for temporary ones.

17. A horizontal beam should have a part of its length equal to its width firmly bearing on the support at each end, and more if possible. A pillar can not have a greater bearing surface than its end section. Crushing effect may be reduced by interposing a hardwood plank or sheet of iron between the end of the beam and its support.

TABLE VIII.

21. Dimensions and widths of angles of equal legs:

Size.	Thickness.	Weight per foot.
Inches.	*Inch.*	*Pounds.*
6 x 6	3/8	14.8
6⅛ x 6⅛	15/16	35.9
5 x 5	3/8	12.3
5⅛ x 5⅛	15/16	29.4
4 x 4	5/16	8.2
4⅛ x 4⅛	3/4	18.6
3½ x 3½	5/16	7.1
3⅝ x 3⅝	5/8	13.7
3 x 3	1/2	8.6
2¾ x 2¾	1/4	4.5
2½ x 2½	3/16	3.1
2⅝ x 2⅝	1/2	7.8
2¼ x 2¼	3/16	2.7
2 7/16 x 2 7/16	3/8	5.4
2 x 2	3/16	2.5
2 1/16 x 2 1/16	3/8	4.8
1¾ x 1¾	3/16	2.1
1 13/16 x 1 13/16	3/8	4.1
1½ x 1½	1/8	1.2
1⅝ x 1⅝	3/8	3.5
1¼ x 1¼	1/8	1.0
1⅜ x 1⅜	1/4	2.0
1⅛ x 1⅛	1/4	1.5
1 x 1	1/8	.8

22. Average ultimate tensile strength in pounds per square inch of various metals:

Brass wire, unannealed or hard	80,000
Brass wire, annealed	63,000
Copper bolts	33,000
Copper wire, hard or unannealed	60,000
Copper wire, annealed	32,000
Cast iron, ordinary pig	14,500
Iron, wrought	45,000
Iron wire, annealed	45,000
Iron wire, unannealed or hard	75,000
Iron-wire rope, per square inch of section of rope	38,000
Phosphor-bronze wire, hard	150,000
Phosphor-bronze wire, annealed	63,000
Steel wire, soft	68,000
Steel wire, medium	76,000
Steel wire, hard	85,000
Steel, rivet	55,000
Steel, cast	60,000

FASTENING MATERIALS.

23. **Rope and wire.**—Much confusion is caused by two methods in common use to denote the size of rope. In marine use it is indicated by the circumference in inches; on land the practice is not uniform, but the use of the diameter in inches is prevalent. The former method is used by manufacturers and is correct as a matter fact. The same rope is called 3-inch or 1-inch by the two systems.

It is practically 3 inches in circumference, but only approximately 1 inch in diameter. It is better to state which dimension is used.

The strength of hemp and jute rope varies; pieces from the same coil differ as much as 25 per cent. Rope made from manila hemp is the best. Other hemp, sisal, and jute ropes are very unreliable in strength. Tarring rope increases its weight and lessens its strength, but adds to its durability. Use and exposure weaken rope 20 per cent to 50 per cent in a few months. Ropes shorten when wet and lengthen when dry.

TABLE IX.

24. **Dimensions, weight, and strength of manila rope:**

Diameter.	Circumference.	Weight in pounds per 100 feet.	Breaking load.	Proper working load depending upon age and condition.
Inches.	*Inches.*		*Pounds.*	*Pounds.*
0.32	1	3.3	780	120- 390
.48	1½	7.4	1,600	250- 800
.64	2	13.2	2,730	350- 1,300
.80	2½	20.6	4,300	600- 2,000
.96	3	29.7	6,100	900- 2,800
1.11	3½	40.4	8,500	1,100- 4,000
1.27	4	52.8	11,600	1,500- 5,000
1.43	4½	66.8	15,000	2,000- 6,500
1.59	5	82.5	18,400	2,600- 8,000
1.75	5½	99.8	22,000	3,000-10,000
1.91	6	119	25,500	3,500-11,500
2.07	6½	139	29,100	4,000-13,000
2.23	7	162	32,700	4,600-15,000
2.39	7½	186	36,300	5,000-16,000

Up to 5 inches circumference rope is made in coils of 1,200 feet each.

25. Ordinary *wire rope* is composed of 6 strands, each containing 7 or 19 wires, laid up about a hemp or wire strand center. Rope with hemp center is more flexible than that with a wire center. The 19-wire rope with hemp center is better adapted to power transmission; the 7-wire rope is used for standing rigging, as derrick guys and other purposes where frequent bending is not involved.

The *safe load* on wire ropes is from one-fifth to one-seventh of the breaking load.

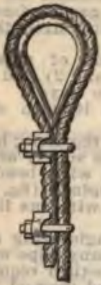


Fig.1

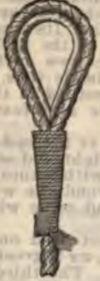


Fig.2

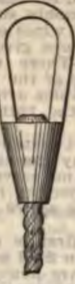


Fig.3

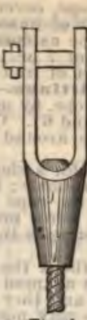


Fig.4

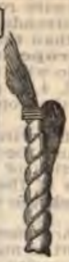
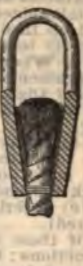


Fig.5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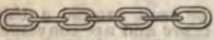


Fig.7

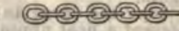


Fig.8

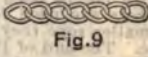


Fig.9

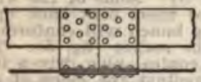


Fig.10

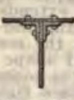


Fig.11

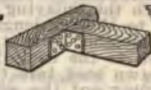


Fig.12

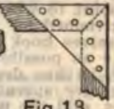


Fig.13

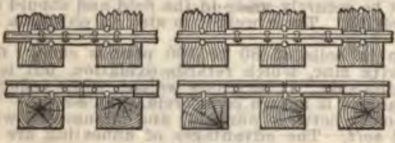


Fig.14

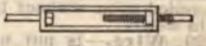


Fig.15

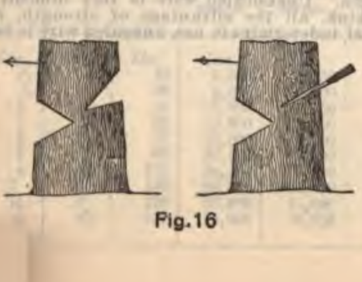


Fig.16

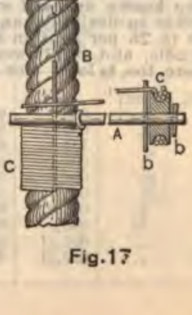


Fig.17

TABLE XII.

30. **Size, weight, and strength** of black charcoal **iron wire;** authority, Trenton Iron Co.; the sizes of corresponding numbers are those of the Trenton Iron Co. and are almost identical with the "new British W gauge"

No.	Diameter.	Linear feet to the pound.	Approximate tensile strength.
	Inches.		*Pounds.*
6	0.1900	10.453	2,476
7	.1750	12.322	2,136
8	.1600	14.736	1,813
9	.1450	17.950	1,507
10	.1300	22.333	1,233
11	.1175	27.340	1,010
12	.1050	34.219	810

If the quality of the wire is not known, the tensile strength in the table should be reduced 15 per cent. For soft Bessemer steel wire they may be increased 10 per cent.

Wire should always be taken from the *outside* of the coil by placing the coil on an axle or rod and walking away with the end or by holding the outer end and rolling the coil along the ground.

31. **Chains** are designated by the diameter of the rod from which the links are made, as ½ inch, 1 inch, etc.

Also by the form of the link, as *close link,* in which one link is just large enough to inclose the two adjacent ones (fig. 8); *open link,* in which the link is larger than in close link (fig. 7); *bar chain,* which consists of open links with a bar across the middle of each; and *twisted link* (fig. 9), in which each link is twisted through a certain angle, usually 90°, and *straight* or *flat link* (figs. 7 and 8), which is not so twisted.

Chain is also *galvanized* or *black,* the latter most used.

TABLE XIII.

32. **Size, weight, and strength** of iron **chains;** authority, Trautwine; strength taken at 1.4 that of the rod of which the links are made.

Size of chain.	Weight per foot.[1]	Breaking strain.	Size of chain.	Weight per foot.[1]	Breaking strain.
Inches.	*Pounds.*	*Pounds.*	*Inches.*	*Pounds.*	*Pounds.*
¼	0.8	3,069	⅞	8.0	37,632
⅜	1.7	6,922	1	10.7	49,280
½	2.5	12,320	1⅛	12.5	59,226
⅝	4.3	19,219	1¼	16.0	73,114
¾	5.8	27,687	1½	21.7	105,280

[1] Weights given are for close link. Open link will weigh less.

33. **Serving.**—On wire or manila rope and with wire or marlin, serving is best done as indicated in figure 17. Provide a bar, *A*, 18 inches to 24 inches long, smooth, and rounded, with cross pins *bb* near one end, the outer one removable, to form a reel for the coil of serving wire *C*.

Lay the free end of the wire along the rope from the point *B*, where the serving is to end, to the point *C*, where it is to begin; make a short bent at the latter and pass the wire twice around the rope over the straight part, half around the bar, around the rope in the opposite direction, and place the coil between the pins, as shown. Rotate the bar around the rope, keeping the following turns close together and the leading turn as taut as may be necessary to get the proper tension. When the following turn has reached *B*, cut off the wire and twist its end with the end of the straight wire, coming out from under the turns.

34. *Driftbolts, spikes, nails,* and wooden *pins* or *treenails* are used for fastening together parts of wooden frames or structures. For driftbolts and treenails, a hole is first bored of slightly less diameter than the bolt or pin. Fastenings of this sort depend upon friction to hold together the parts that are joined. Design joints to avoid as far as possible a heavy shearing stress on the fastenings.

Driftbolts are iron bars of square or circular cross section, headed more or less at one end and bluntly pointed at the other. The head is often omitted, as a small one is made in driving. All bolts, spikes, and nails should be of such length that when driven the point will rest in solid wood.

TABLE XIV.

35. **Dimensions** and **weights** of **driftbolts:**

Length.	Square section side.		Round section, diameter.	
	¾ inch.	1 inch.	¾ inch.	1 inch.
Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
18	2.9	5.1	2.3	4.0
20	3.2	5.7	2.5	4.4
22	3.5	6.2	2.8	4.9
24	3.8	6.8	3.0	5.4
26	4.1	7.3	3.3	5.8

36. Wood joints may also be secured with screw bolts or lag screws.

Screw bolts are of round iron with square heads forged at one end and standard screw threads cut on the other. Nuts should be square, with a thickness equal to the diameter of the bolt and a side equal to twice the diameter. Cast-iron washers should be placed under the nut, and under the head also if the timber is soft.

Lag screws are large gimlet-pointed wood screws with square heads to be turned with a wrench instead of a screw driver. The timber next to the head should be bored the full size of the shank; rest of the hole should be smaller, and its total length somewhat than that of the screw. Wrought-iron washers should be placed er the head.

TABLE XV.

37. **Dimensions** and approximate **weights** of **screw bolts** in pounds, including square head and nut:

Length under head.	Diameter.				
	½ inch.	⅝ inch.	¾ inch.	⅞ inch.	1 inch.
Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
6	0.59	1.01	....	....	....
7	.64	1.10	....	....	....
8	.70	1.19	....	....	....
9	.75	1.27	....	....	....
10	.81	1.36	2.10	3.05	4.23
11	.86	1.44	2.22	3.22	4.45
12	.92	1.53	2.35	3.39	4.67
13	.97	1.62	2.47	3.55	4.89
14	1.03	1.70	2.59	3.72	5.11
15	1.08	1.79	2.72	3.89	5.34
16	....	1.87	2.84	4.06	5.56
17	....	1.96	2.97	4.23	5.78
18	....	2.05	3.09	4.40	6.00
19	....	....	3.21	4.57	6.22
20	....	....	3.34	4.74	6.44
21	....	....	3.46	4.90	6.66
22	....	....	3.59	5.07	6.88
23	....	....	3.71	5.24	7.10
24	....	....	3.83	5.41	7.32

TABLE XVI.

38. **Dimensions** and **weights** of wrought-iron **washers:**

Diameter of lag screw.	Diameter of washer.	Diameter of hole.	Thickness, wire gauge.	Number in 150 pounds.	Weight of one.
Inch.	*Inch.*	*Inch.*			*Pound.*
½	1⅜	$\frac{9}{16}$	No. 12	4,500	0.0333
⅝	1¾	$\frac{11}{16}$	No. 10	2,500	.0600
¾	2	$\frac{13}{16}$	No. 10	1,600	.0938

TABLE XVII.

39. **Dimensions** of **steel-wire nails** and approximate **number per pound**, etc.:

Sizes.	Common.		Number per pound.					Length.
	Diameter.		Common.	Fencing.	Box.	Flooring.	Shingle.	
	B.W.G.	Inches.						*Inches.*
2d......	15	0.072	900	....	1,000	....	....	1
3d......	14	.083	615	....	660	....	380	1¼
4d......	12½	.102	322	....	550	....	256	1½
5d......	12½	.102	250	127	366	....	226	1¾
6d......	11½	.115	200	114	250	151	200	2
7d......	11½	.115	154	88	236	136	130	2¼
8d......	10¼	.124	106	74	157	98	120	2½
9d......	10¼	.124	85	58	145	86	115	2¾
10d......	9	.148	74	42	107	66	79	3
12d......	9	.148	57	36	98	51	....	3¼
16d......	8	.165	46	28	65	40	....	3½
20d......	6	.203	29	22	45	29	....	4
30d......	5	.220	23	....	40	....	....	4½
40d......	4	.238	17	....	30	....	....	5
50d......	3	.259	13½	....	....	....	....	5½
60d......	2	.284	10½	....	....	....	....	6

TABLE XVIII.

40. **Dimensions** of miscellaneous **steel-wire nails** and approximate **number per pound.**

B. W. G.	Diameter.	Lengths, inches.															
		2	2¼	2½	2¾	3	3½	4	4½	5	6	7	8	9	10	11	12
	Ins.																
00	0.380	20	18	16	15	14	12	10	9	8	7	6	5	4	4	3	3
⅜	.375	20	18	16	15	14	12	10	9	8	7	6	5	4	4	3	3
0	.340	21	19	17	16	15	13	11	10	9	8	7	5	5	4	4	3
5/16	.313	28	25	23	21	19	16	14	13	11	10	8	7	6	6	5	4
2	.284	32	29	26	24	22	19	16	14	13	11	9	8	7	6	6	5
3	.259	38	34	30	28	25	22	19	17	15	13	11	10	8	7	...	...
4	.238	45	40	36	33	30	26	23	20	18	15	13	11	10	9	...	...
5	.220	53	47	42	39	35	30	26	24	21	18	15	....	....	...	...	...
6	.203	62	55	50	45	41	35	31	28	25	21	18	....	....	...	...	...
7	.180	75	67	60	54	50	43	37	33	30	25	....	....	....	...	...	...
8	.165	86	76	69	62	57	49	43	39	35	29	....	....	....	...	...	...
9	.148	103	92	82	75	69	59	52	46	41	....	....	....	....	...	...	...
10	.134	124	110	99	90	83	71	62	55	50	....	....	....	....	...	...	...
11	.120	57	139	125	114	105	90	79	70	....	....	....	....	....	...	...	...
12	.109	204	182	164	149	137	117	103	....	....	....	....	....	....	...	...	...
13	.095	268	238	214	195	178	153	....	....	....	....	....	....	....	...	...	...
4	.083	350	315	284	258	236	....	....	....	....	....	....	....	....	...	...	...
5	.072	438	389	350	....	....	....	....	....	....	....	....	....	....	...	...	...

TABLE XIX.

41. **Dimensions** of square **boat spikes** and approximate **number** in a **keg** of 200 pounds:

Size.	Length of spike, inches.											
	3	4	5	6	7	8	9	10	11	12	14	16
In.												
$\frac{1}{4}$	3,000	2,375	2,050	1,825	......	......	......	......	......	......	......	....
$\frac{5}{16}$	1,660	1,360	1,230	1,175	990	880	......	......	......	......	......	....
$\frac{3}{8}$	1,320	1,140	940	800	650	600	525	475	......	......	......	....
$\frac{7}{16}$	......	......	......	600	500	510	440	360	320	218	......	....
$\frac{1}{2}$	......	......	......	450	375	335	300	275	260	240	......	....
$\frac{5}{8}$	......	......	......	......	......	260	240	220	205	190	175	160

TABLE XX.

42. **Dimensions** of **railroad spikes:**

Size measured under head.	Average number per keg 200 pounds.	Quantity of spikes per mile of single track; ties 2 feet c. to c., 4 spikes per tie.		Rail used, weight per yard.
Inches.		*Pounds.*	*Kegs.*	*Pounds.*
$5\frac{1}{2}$ x $\frac{5}{8}$	300	7,040	$35\frac{1}{5}$	75-100
$5\frac{1}{2}$ x $\frac{9}{16}$	375	5,870	$29\frac{1}{3}$	45-75
5 x $\frac{9}{16}$	400	5,170	26	40-56
5 x $\frac{1}{2}$	450	4,660	$23\frac{1}{3}$	35-40
$4\frac{1}{2}$ x $\frac{1}{2}$	530	3,960	20	30-35
4 x $\frac{1}{2}$	600	3,520	$17\frac{3}{5}$	25-35
$4\frac{1}{2}$ x $\frac{7}{16}$	680	3,110	$15\frac{1}{2}$	20-30
4 x $\frac{7}{16}$	720	2,910	$14\frac{3}{4}$	20-30
$3\frac{1}{2}$ x $\frac{7}{16}$	900	2,350	11	16-25
4 x $\frac{3}{8}$	1,000	2,090	$10\frac{1}{2}$	16-25
$3\frac{1}{2}$ x $\frac{3}{8}$	1,190	1,780	9	16-20
3 x $\frac{3}{8}$	1,240	1,710	$8\frac{1}{2}$	16-20
$2\frac{1}{2}$ x $\frac{3}{8}$	1,342	1,575	$7\frac{7}{8}$	8-16

43. **Joints** in **metal** are made with screw bolts already described, or with rivets. With bolts the holes should come fair when the pieces are assembled and the bolt should fit snugly in the hole; abutting surfaces should be well painted before assembling to exclude moisture. In riveted joints it is equally important that the holes come fair, but the rivet should fit loosely in the hole. Bolted joints are much more conveniently made, especially in the field, but they have less strength than the riveted ones.

Joints in metal are most frequently made by the use of auxiliary pieces such as *butt straps, angle plates, gusset plates, angle irons*, etc. Some common forms are shown in figures 10 to 15.

44. **Felling trees.**—If convenient, arrange for the tree to fall in the direction of its natural inclination. If it be necessary to fell in another direction, use ropes to pull the tree partly over before the cutting is finished. Commence cutting with the ax on the side

toward which the tree is to fall; cut as far as the center of the tree or a little beyond, as in figure 16; then change to the opposite side and commence cutting slightly above the former cut, continuing until the tree falls. If experienced axmen be lacking, better results can be obtained with crosscut saws. Cut from the falling side until the saw begins to jamb, then cut from the other side until the tree falls. Both saw and ax may be used.

45. **Framing.**—The following methods are applicable to joining the sills and caps to the posts of wooden trestles:

By *driftbolts* (fig. 33), two through the foot of each post into the sill and one through the cap into the post.

By using *split caps* and *sills* (figs. 31 and 32). Instead of a single stick of timber two pieces of half the width are used. For example, a 12 by 12 inch cap or sill is replaced by two 6 by 12 inch sticks. A tenon 3 to 6 inches thick and the full width of the post is made on its top. One of the cap or sill pieces is placed on each side of the tenon and held in place by bolts at each post.

By *fish plates* and *bolts,* as in figure 37.

Figures 18 to 30 show various useful forms of joints.

KNOTS.

46. The following knots are most useful in bridging:

Overhand knot (fig. 38*a*), used at the end of a rope to prevent unreeving or to prevent the end of the rope from slipping through a block.

Figure-of-eight knot (fig. 38*b*), used for purposes similar to above.

Square or *reef knot* (fig. 38), commonly used for joining two ropes of the same size. The standing and running parts of each rope must pass through the loop of the other in the same direction, i. e., from above downward or vice versa; otherwise a *granny* (fig. 39) is made, which is a useless knot that will not hold. The reef knot can be upset by taking one end of the rope and its standing part and pulling them in opposite directions. With dry rope a reef knot is as strong as the rope; with wet rope it slips before the rope breaks, while a double sheet bend is found to hold.

The *thief knot* (fig. 40), commonly mistaken for a reef knot, should be avoided as it will not hold. The figure shows that the end of each rope turns around the standing part instead of around the end of the other, as in a reef knot.

Single sheet bend, weaver's knot (fig. 41), used for joining ropes together, especially when unequal in size. It is more secure than the reef knot but more difficult to untie.

Double sheet bend (fig. 42), used also for fastening ropes of unequal sizes, especially wet ones, and is more secure than the single sheet bend.

Two half hitches (fig. 43), especially useful for belaying, or making fast the end of a rope round its own standing part. The end may be lashed down or seized to the standing part with a piece of spun yarn; this adds to its security and prevents slipping.

This knot should never be used for hoisting a spar.

Round turn and *two half hitches* (fig. 44), like the preceding, except that a turn is first taken round the spar or post.

Fisherman's bend or *anchor knot* (fig. 45), used for fastening a rope to a ring or anchor. Take two turns round the iron, then a half hitch round the standing part and between the rings and the turns, lastly a half hitch round the standing part.

Clove hitch (fig. 46), generally used for fastening a rope at right angles to a spar or at the commencement of a lashing. If the end of the spar is free, the hitch is made by first forming two loops, as in fig. 47, placing the right-hand loop over the other one and slipping
ouble loop (fig. 48) over the end of the spar. If this can not
, pass the end of the rope round the spar, bring it up to the
the standing part, cross over the latter, make another turn

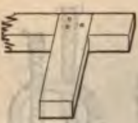


Fig. 18.

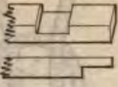


Fig. 19.

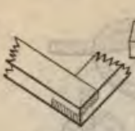


Fig. 20.

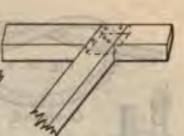
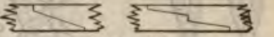


Fig. 21.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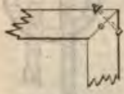
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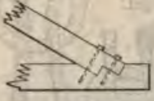
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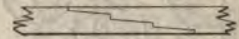


Fig. 25.

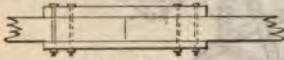


Fig..26.

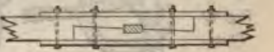


Fig. 27.

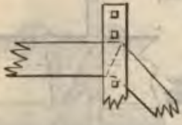


Fig. 28.

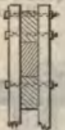


Fig. 29.

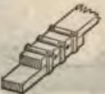


Fig. 30.

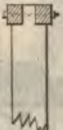


Fig. 31.

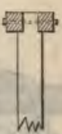


Fig. 32.

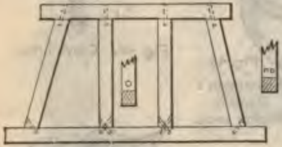


Fig. 33.

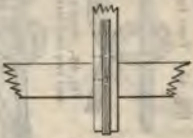


Fig. 34.

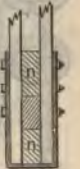


Fig. 35.

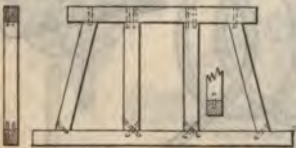


Fig. 36.

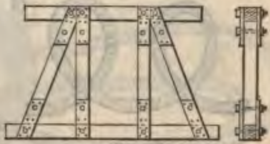


Fig. 37.

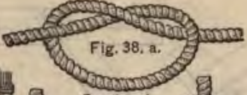


Fig. 38. a.

Overhand.

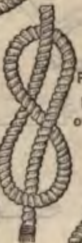


Fig. 38. b.

Figure of eight.

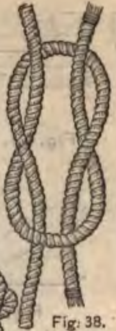


Fig. 38.

Square or Reef.

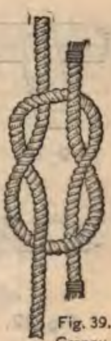


Fig. 39.

Granny.

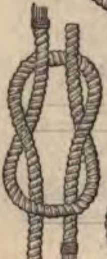


Fig. 40.

Thief.

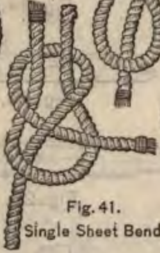


Fig. 41.

Single Sheet Bend.

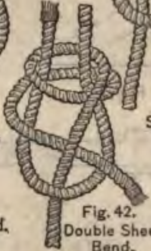


Fig. 42.

Double Sheet Bend.

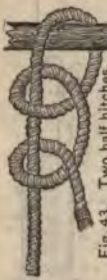


Fig. 43. Two half hitches.

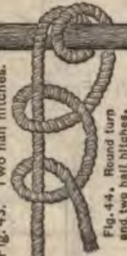


Fig. 44. Round turn and two half hitches.

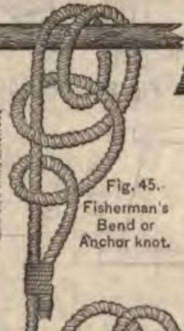


Fig. 45.

Fisherman's Bend or Anchor knot.

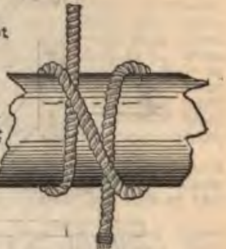


Fig. 46. Clove hitch.

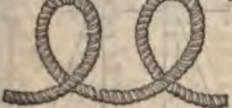


Fig. 47.

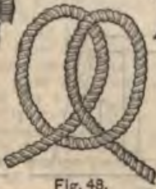


Fig. 48.

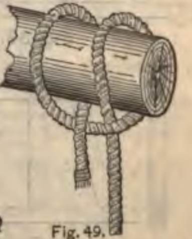


Fig. 49.

Clove hitch.

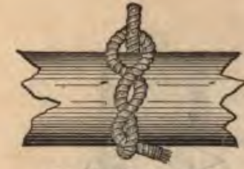


Fig. 50. Timber hitch.

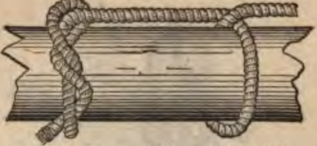


Fig. 51. Timber hitch and Half hitch.

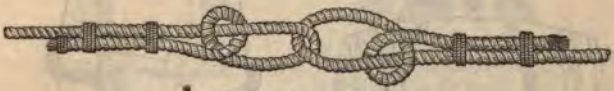


Fig. 53. Hawser Bend

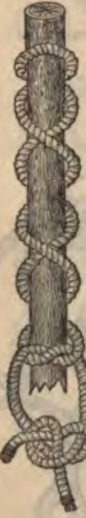


Fig. 52. Telegraph hitch.

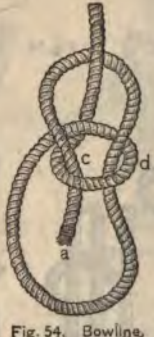


Fig. 54. Bowline.

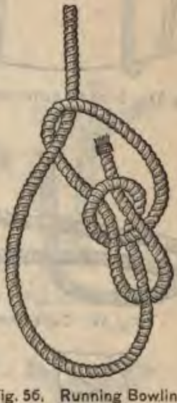


Fig. 56. Running Bowline.

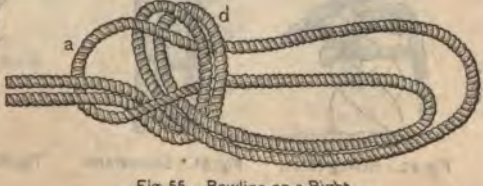


Fig. 55. Bowline on a Bight.

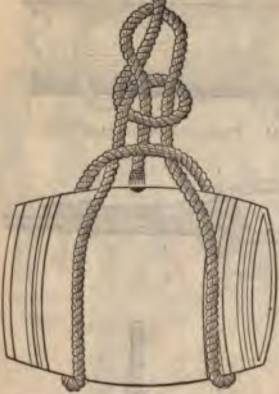


Fig. 57. Sling for barrel horizontal.

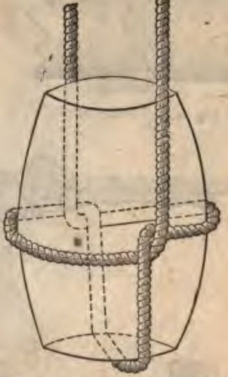


Fig. 58. Sling for barrel vertical.

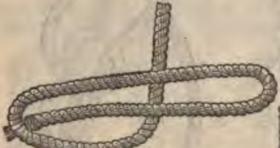


Fig. 59. Cat's Paw. a.

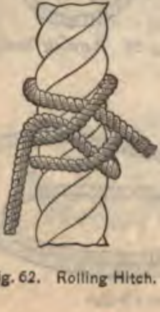


Fig. 62. Rolling Hitch.

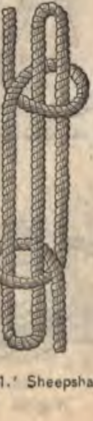


Fig. 61. Sheepshank.

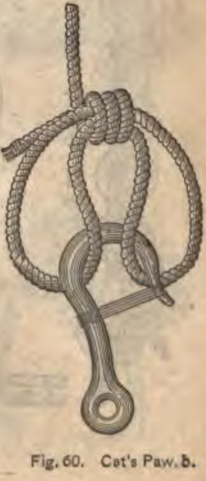


Fig. 60. Cat's Paw. b.

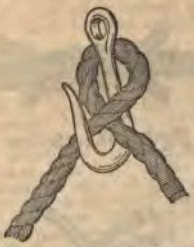


Fig. 63. Blackwall Hitch.

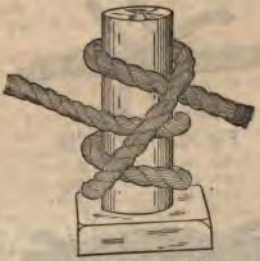


Fig. 64. Mooring Knot.

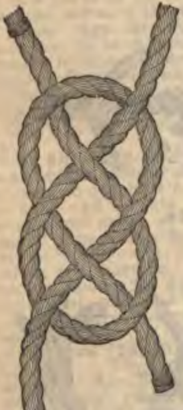


Fig. 65.
Carrick Bend.

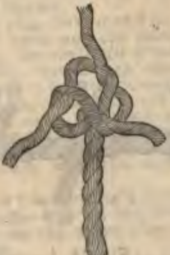


Fig. 66. Wall Knot.

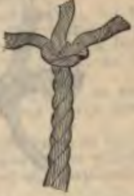


Fig. 67. Wall Knot.

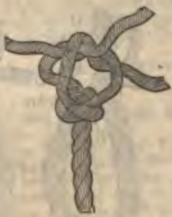


Fig. 68.

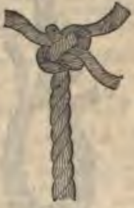


Fig. 69.

Crown on Wall.

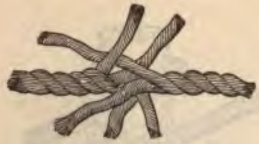


Fig. 70. Short Splice.

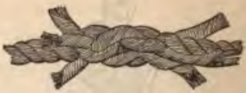


Fig. 71. Short Splice.

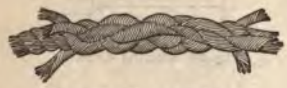


Fig. 72. Short Splice.

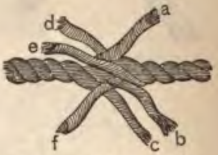


Fig. 73. Long Splice.

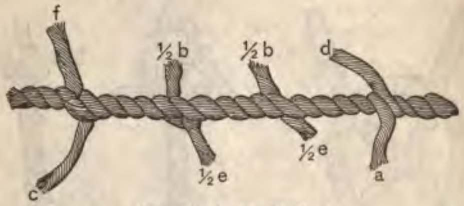


Fig. 74. Long Splice.

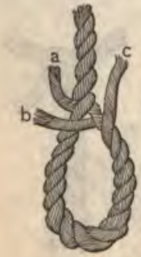


Fig. 75.

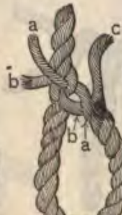


Fig. 75a.

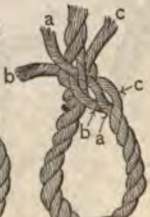


Fig. 76.

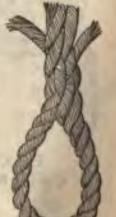


Fig. 76a.

round the spar, and bring up the end between the spar, the last turn, and the standing part (fig. 49). When used for securing guys to sheer legs, etc., the knot should be made with a long end, which is formed into two half hitches round the standing part and secured to it with spun yarn.

Timber hitch (fig. 50), used for hauling and lifting spars. It can easily be loosed when the strain is taken off, but will not slip under a pull. When used for hauling spars, a half hitch is added near the end of the spar (fig. 51).

Telegraph hitch (fig. 52), used for hoisting or hauling a spar.

Hawser bend (fig. 53), used for joining two large cables. Each end is seized to its own standing part.

Bowline (fig. 54), forms a loop that will not slip. Make loop with the standing part of the rope underneath, pass the end from below through the loop, over the part round the standing part of the rope, and then down through the loop *c*. The length of bight depends upon the purpose for which the knot is required.

Bowline on a bight (fig. 55). The first part is made like the above, with the double part of a rope; then the bight *a* is pulled through sufficiently to allow it to be bent past *d* and come up in the position shown. It makes a more comfortable sling for a man than a single bight.

Running bowline (fig. 56).

To sling a barrel or box horizontally (fig. 57) make a bowline with a long bight and apply it as shown.

To sling a barrel vertically (fig. 58), make an overhand knot on top of the two parts of the rope; open out the knot and slip each half of it down the sides of the cask; secure with a bowline.

Cat's-paw (figs. 59 and 60). Form two equal bights, as in figure 59; take one in each hand and roll them along the standing part till surrounded by three turns of the standing part; then bring both loops (or bights) together and pass over the hook of a block, as in figure 60, where the hook is shown moused with yarn.

Sheep shank (fig. 61), used for shortening a rope or to pass by a weak spot; a half hitch is taken with the standing parts around the bights.

Rolling hitch (fig. 62), used for hauling a larger rope or cable. Two turns are taken around the large rope in the direction in which it is to be hauled and one half hitch on the other side of the hauling part. A useful knot and quickly made.

For armored cable, or wet manila rope, the hitch must be made with a strap of rope yarn (fig. 86). Rope will not hold.

Blackwall hitch (fig. 63), used for attaching a single rope to a hook of a block for hoisting.

Mooring knot (fig. 64). Take two turns around the mooring or snubbing post, pass the free end of the rope under the standing part; take a third turn above the other and pass the free end between the two upper turns.

Carrick bend (fig. 65), much used for hawsers and to fasten guys to derricks.

Wall knot (figs. 66 and 67) and

Crown on wall (figs. 68 and 69); both used for finishing off the ends of ropes to prevent unstranding.

To make a *short splice* (figs. 70, 71, and 72) unlay the strands of each rope for a convenient length. Bring the rope ends together so that each strand of one rope lies between the two consecutive strands of the other rope. Draw the strands of the first rope along the second and grasp with one hand. Then work a free strand of the second rope over the nearest strand of the first rope and under the second strand, working in a direction opposite to the twist of the rope. The same operation applied to all the strands will give the result shown by figure 71. The splicing may be continued in the same manner to any extent (fig. 72), and the free ends of the strands may be cut off when desired. The splice may be neatly tapered by cutting out a few fibers from each strand each time it is passed through the rope. Rolling under a board or the foot will make the splice compact.

Long splice (figs. 73, 74).—Unlay the strands of each rope for a convenient length and bring together as for a short splice. Unlay to any desired length a strand, *d*, of one rope, laying in its place the nearest strand, *a*, of the other rope. Repeat the operation in the opposite direction with two other strands, *c* and *f*. Figure 74 shows strands *c* and *f* secured by tying together. Strands *b* and *e* are shown secured by unlaying half of each for a suitable length and laying half of the other in place of the unlayed portions, the loose ends being passed through the rope. This splice is used when the rope is to run through a block. The diameter of the rope is not enlarged at the splice. The ends of the strands should not be trimmed off close until the splice has been thoroughly stretched by work.

Eye splice (figs. 75, 75*a*, 76, 76*a*).—Unlay a convenient length of rope. Pass one loose strand, *a*, under one strand of the rope, as shown in figure 75, forming an eye of the proper size. Pass a second loose strand, *b*, under the strand of the rope next to the strand which secures *a* (fig. 75*a*). Pass the third strand, *c*, under the strand next to that which secures *b* (fig. 76). Draw all taut and continue and complete as for a short splice.

LASHINGS.

47. *To lash a transom to an upright spar* (fig. 77), transom in front of upright.—A clove hitch is made round the upright a few inches below the transom. The lashing is brought under the transom, up in front of it, horizontally behind the upright, down in front of the transom, and back behind the upright at the level of the bottom of the transom and above the clove hitch. The following turns are kept outside the previous ones on one spar and inside on the other, not riding over the turns already made. Four turns or more are required. A couple of frapping turns are then taken between the spars, around the lashing, and the lashing is finished off either round one of the spars or any part of the lashing through which the rope can be passed. The final clove hitch should never be made around the spar on the side toward which the stress is to come, as it may jam and be difficult to remove. The lashing must be well beaten with handspike or pick handle to tighten it up. This is called a square lashing.

48. *Lashing for a pair of shears* (fig. 78).—The two spars for the shears are laid alongside of each other with their butts on the ground, the points below where the lashing is to be resting on a skid. A clove hitch is made round one spar and the lashing taken loosely eight or nine times about the two spars above it without riding. A couple of frapping turns are then taken between the spars and the lashing is finished off with a clove hitch above the turns on one of the spars. The butts of the spars are then opened out and a sling passed over the fork, to which the block is hooked or lashed, and fore and back guys are made fast with clove hitches to the bottom and top spars, respectively, just above the fork (fig. 79).

49. *To lash three spars together as for a gin or tripod.*—Mark on each spar the distance from the butt to the center of the lashing. Lay two of the spars parallel to each other with an interval a little greater than the diameter. Rest their tips on a skid and lay the third spar between them with its butt in the opposite direction so that the marks on the three spars will be in line. Make a clove hitch on one of the outer spars below the lashing and take eight or nine loose turns around the three, as shown in figure 80. Take a couple of frapping turns between each pair of spars in succession and finish with a clove hitch on the central spar above the lashing. Pass a sling over the lashing and the tripod is ready for raising.

50. ***Holdfasts.***—To prepare a fastening in the ground for the *ttachment of guys* or purchases, stout pickets are driven into the *ound one behind the other*, in the line of pull. The head of each

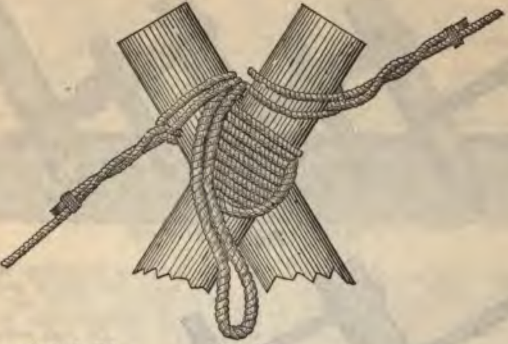


Fig. 79

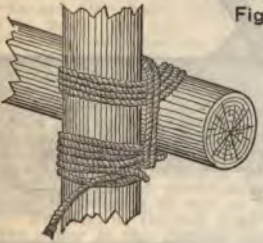


Fig. 77

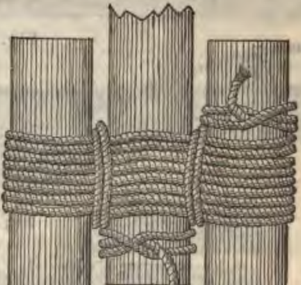


Fig. 80

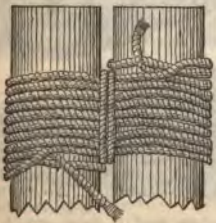


Fig. 78

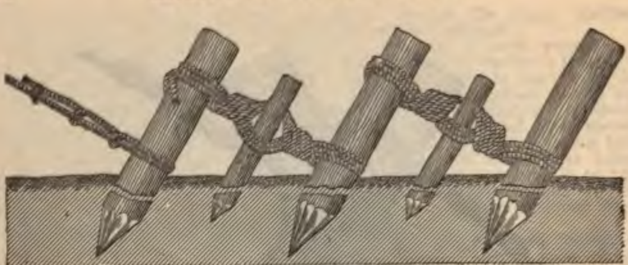


Fig. 81

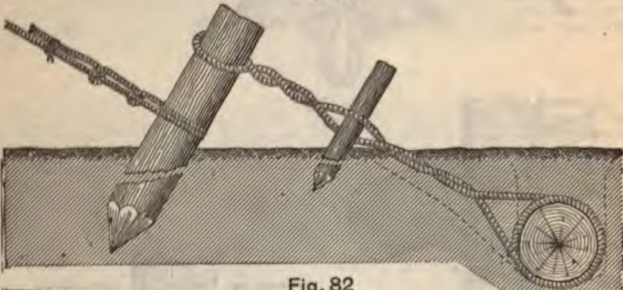


Fig. 82

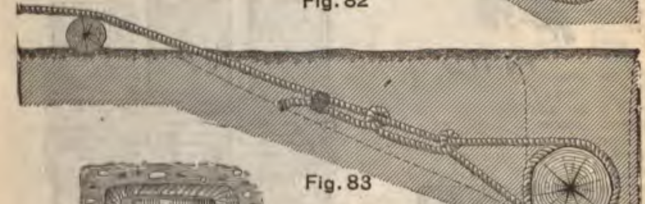


Fig. 83

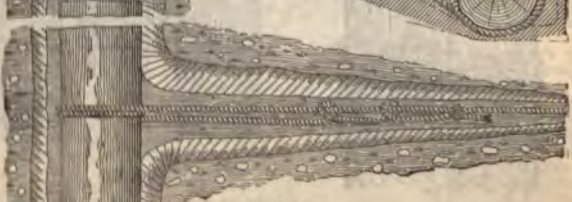


Fig. 84

picket except the last is secured by a lashing to the foot of the picket next behind (fig. 81). The lashings are tightened by rack sticks, the points of which are driven into the ground to hold them in position. The distance between the stakes should be several times the height of the stake above the ground.

Another form requiring more labor but having much greater strength is called a "*deadman*," and consists of a log laid in a transverse trench with an inclined trench intersecting it at its middle point. The cable is passed down the inclined trench, takes several round turns on the log, and is fastened to it by half hitches and marlin stopping (figs. 82, 83, and 84). If the cable is to lead horizontally or inclined downward, it should pass over a log at the outlet of the inclined trench (fig. 83). If the cable is to lead upward, this log is not necessary, but the anchor log must be buried deeper.

BLOCKS AND TACKLES.

51. The parts of a block are the *shell* or *frame*, the *sheave* or *wheel* upon which the rope runs, and the *pin* upon which the wheel turns in the shell. A *strap* of iron or rope passes around the shell and forms attachments for a *hook* at one end and an *eye* at the other. (See figs. 85, 86, 87, and 88.)

Blocks are also made entirely of metal, in which the strap is replaced by bolts (fig. 89).

Blocks are designated by the length of the shell in inches and by the number of their sheaves. Those with one, two, three, and four sheaves are called *single*, *double*, *triple*, and *quadruple*. The largest rope a wooden block will take has a circumference equal to one-third the length of the shell. Self-lubricating blocks may be obtained and are to be preferred.

A *snatch block* is a single block with the shell and strap open at one side to admit a rope without passing the end through (fig. 90).

A *running block* is attached to the object to be moved; a *standing block* is fixed to some permanent support (figs. 94, 95, and 96). A *simple tackle* consists of one or more blocks rove with a single rope or fall. The end of the fall fixed in the tackle is called the standing end; the other is the running end. Each part of the fall between the two blocks, or between either end and the block, is called a *return*.

To *overhaul* is to separate the blocks; to *round in*, to bring them closer together. When the blocks are in contact the fall is said to be *chockablock*.

A *whip* is a single fixed block and fall; it gives no increase of power. A whip on a whip (fig. 98) doubles its power.

A *luff tackle* consists of a single and a double block, either fixed or movable (fig. 94).

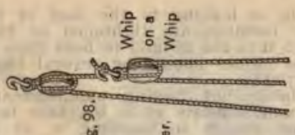
A *gun tackle* consists of a double and a single block, the standing end attached to the fixed block (fig. 95).

GENERAL NOTES ON BRIDGE DESIGN.

52. When frequent supports can be obtained, the floor system, consisting of longitudinal beams and cross planking, or their equivalents, rests directly on piers. This method of construction should be adopted whenever practicable. If long spans are necessary, the floor system must be sustained by *cantilevers*, *trusses*, *arches*, or *cables* resting on the supports and forming cantilever, truss, arched, or suspension bridges.

53. A roadway 9 feet wide in the clear should be provided to pass infantry in fours, cavalry two abreast, and military wagons in one direction; a width of 6 feet will suffice for infantry in column of twos, cavalry in single file, and field guns passed over by hand.

The *clear width* of roadway of an ordinary highway bridge should *not be less* than 12 feet for single track or 20 feet for double track.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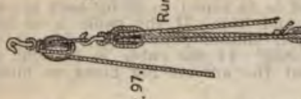
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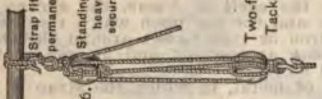
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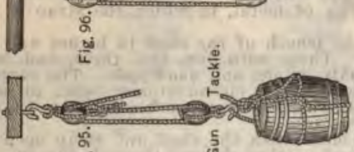
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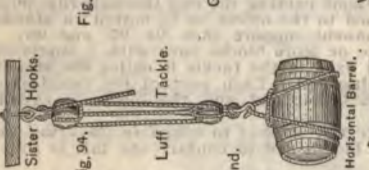
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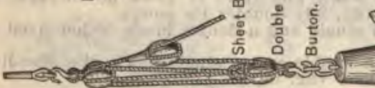
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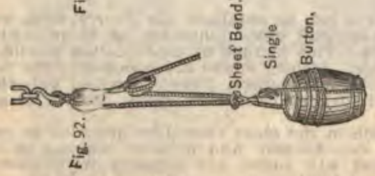
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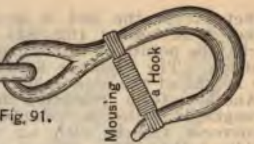
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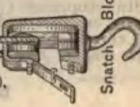
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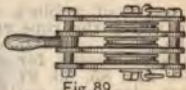
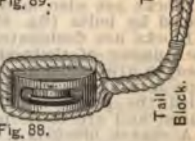


Fig. 89.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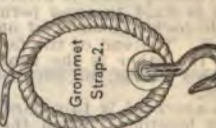
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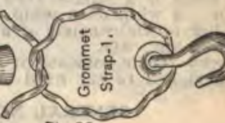


Fig. 86.

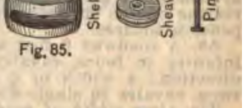


Fig. 85.

The *clear head room* in ordinary military bridges should not be less than 9 feet for wagons and cavalry; for highway bridges not less than 14 feet.

Ramps at the ends of a bridge, if intended for artillery, should not be steeper than 1 on 7. For animals, slopes steeper than 1 on 10 are inconvenient.

If the bridges are high, hand rails should be provided. A single rope may suffice, or it may have brush placed upon it to form a screen.

A guard rail should be provided along each side of the roadway, near the ends of the flooring planks. In hasty bridges it may be secured by a lashing or lashings through the planking to the stringer underneath. Otherwise it may be fastened with spikes or bolts.

54. Examples of **improvised short-span** military bridges:

Trussed ladder bridge.—A ladder may be used as a bridge by placing it on its edge, thus forming a kind of trussed beam. A portable bridge of this kind was used in China in 1860 for crossing canals. Two beams 24 feet long were formed out of four scaling ladders, each 12 feet long, by lashing them in pairs end to end, with planks 3 feet long covering the junctions. The beams so made were laid across the canal, set on edge in grooves cut into the bank. Planks 4 feet long were laid across from beam to beam to form the roadway (fig. 99).

This bridge, 24 feet long, was laid and crossed in a quarter of an hour. Its total weight was 750 pounds, or 31 pounds per foot. It was crossed by half a company of infantry, two abreast, files well closed and in step.

The ladder beam may be greatly strengthened by trussing with a rope, as shown in figure 100.

In shallow streams intermediate supports may be quickly obtained by moving wagons into the water.

55. **Spar bridges.**—This name is applied to bridges built of round timbers lashed together. Intermediate points of support are provided by inclined frames acting as struts to transmit weight from the middle of the bridge to the banks. The single-lock and double-lock bridges with two and three spans of 15 feet, respectively, are the ones of most utility.

The first step in constructing a spar bridge is to measure the gap to be bridged and select the position of the footings on either bank. Determine the distance from each footing to the middle point of the roadway if a single-lock, or the two corresponding points of a double-lock bridge. Next determine and mark on each spar except the diagonals the places where other spars cross it. The marking may be done with chalk or with an ax. If possible a convenient notation should be adopted. As, for example, in marking with chalk, a ring around the spar where the edge of the crossing spar will come, and a diagonal cross on the part which will be hidden by the crossing spar.

A simple way to determine the length of spars is the following: Take two small lines somewhat longer than the width of the gap, double each and lash the bights together. Stretch them tightly across the gap so that the lashing comes at the middle, as at *A*, figure 109. Release one end of each and stretch it to the footing on the same side as indicated by the dotted lines. Mark each line at the footing *C* or *C'*, and at the position chosen for the abutment sill, *B* or *B'*. Cut the lashing and take each piece of rope to its own side. The distances *AB* and *AB'* are the lengths between the transoms, and with 2 feet added give the length of road bearers required. The distances *AC* and *AC'* are the lengths of struts from butt to top of transom, and with 3 feet added give the total length of spars required.

For a double-lock bridge, a piece of rope of a length equal to the length of the middle bay replaces the lashing. If the banks are not parallel, a measurement should be taken on each side of the bridge.

If desired, a section of the gap may be laid down on the ground in full size and the lengths of spars determined by laying them in place.

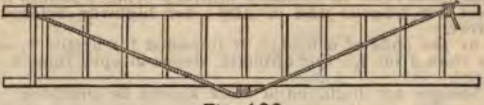
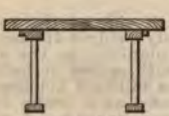


Fig. 100.



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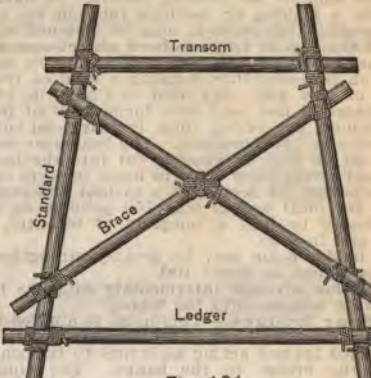

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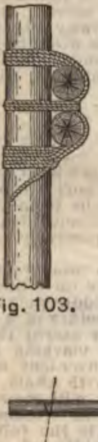

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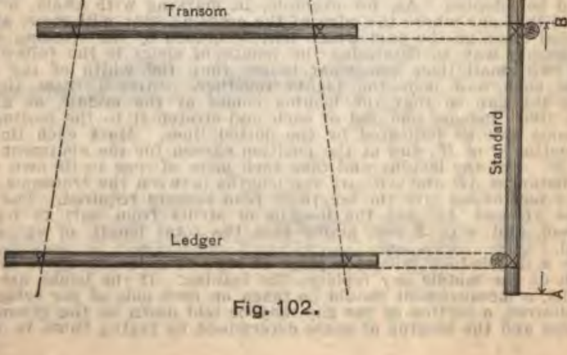

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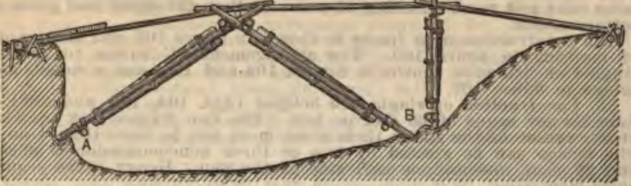

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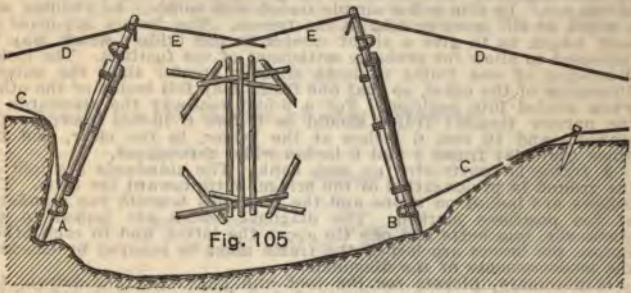


Fig. 105

Fig. 106

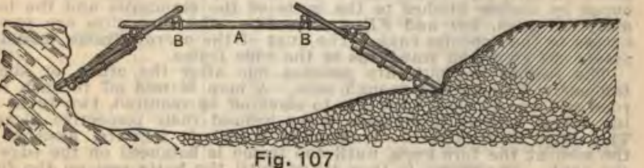


Fig. 107

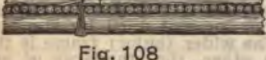


Fig. 108

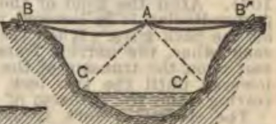


Fig. 109

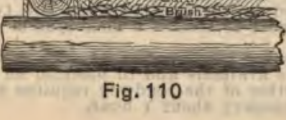


Fig. 110

This method, though given as standard by all authorities, requires more time and more handling of material than the other and gives no better results.

The construction of a frame is shown in figure 101 and the system of marking in figure 102. The arrangement of frames to form a single-lock bridge is shown in figures 104 and 105, and a double-lock bridge in figure 107.

56. *Construction of single-lock bridges* (figs. 104, 105, and 106).—Suitable for spans of 30 feet or less. The two frames lock together at the center of the span; their slope must not be more than 4 on 7. The bridge can be erected by two or three noncommissioned officers and 20 men, one-half on each side of the gap. Heavy spars require more men.

The footings at *A* and *B* must be firm, horizontal if possible, and at right angles to the axis of the bridge. In a masonry pier they may be cut out. In firm soil a simple trench will suffice. In yielding soil a plank or sill must be laid in the trench. The frames are made of such length as to give a slight camber to the bridge, which may be increased to allow for probable settlement of the footings. The inside dimension of one frame is made slightly greater than the outside dimension of the other, so that one frame may fall inside of the other when hauled into position. For a 9-foot roadway the standards of the narrow (inside) frame should be 9 feet 6 inches apart at the transom and 10 feet 6 inches at the ledger, in the clear, and the other (outside) frame 1 foot 6 inches wider throughout.

A frame is constructed on each bank. The standards are laid on the ground in prolongation of the bridge, butts toward the bank. The ledgers are lashed on *above* and the transoms *beneath* the standards at the positions marked. The diagonal braces are lashed to the standards, two butts and one tip above the latter, and to each other. Before the braces are lashed the frame must be squared by checking the measurements of the diagonals.

If necessary, pickets for the foot and guy ropes are driven, the former about 2 paces from the bank and 4 paces on each side of the axis of the bridge; the latter about 20 paces from the bank and 10 paces on each side of the axis. The foot ropes, *CC* (fig. 106), are secured by timber hitches to the butts of the standards and the back and fore guys, *DD* and *EE*, to the tips; the fore guys are passed across to the opposite bank. The guys of the *narrow* frame should be *inside* the guys and standards of the wide frame.

The frames are put into position one after the other, or simultaneously if there are enough men. A man is told off to each foot rope and one to each back guy to slack off as required, two turns being taken with each of these ropes around their respective pickets. The other men raise the frame and launch it forward, assisted by the men at the fore guys, until the frame is balanced on the edge of the bank. The frame is then tilted until the butts rest on the footing, by slacking off the foot ropes and hauling on the fore guys (fig. 106). After the head of the frame has been hauled over beyond the perpendicular it is lowered nearly into its final position by slacking off the back guys. When the two frames are in this position opposite each other, the narrow frame is further lowered until its standards rest upon the transom of the other. The wider (outer) frame is then lowered until the two lock into each other, the standards of each resting upon the transom of the other.

The center or fork transom (figs. 104 and 105) is then passed from shore and placed in the fork between the two frames. This forms the central support to receive a floor system of two bays, built as already described.

The estimated time for construction of such a bridge is about 1 hour if the material is available and in position on both sides of the stream. The construction of the roadway requires about 20 minutes; *forming* footings in masonry about 1 hour.

57. *Construction of double-lock bridge* (fig. 107).—Suitable for spans not exceeding 45 feet and consisting of two inclined frames which lock into a connecting horizontal frame of two or more distance pieces, with cross transoms, dividing the gap to be bridged into three equal bays of about 15 feet. The force required is two or three noncommissioned officers and 25 to 50 men; the time for construction, except roadway, about 2½ hours; extra time to be allowed for difficult footings.

The width of gap is measured, the position of footings determined, and the length of standards from butt to transom determined and marked as before.

The inclined frames in this case are built of equal widths, launched as before, and held by guys just above their final position. Two stringers are launched out from each bank to the main transom. The distance pieces (fig. 107) are put into position inside the standards, using tackle if necessary, and the road transoms are placed and lashed to the distance pieces at the places marked. Both frames are now lowered until they jam.

TABLE XXI.

58. **Round timber** required for **spar bridges:**

Kind of bridge.	Spars.	Length.	Diameter.		Purpose.
			At tip.	Throughout or mean.	
	Number.	*Feet.*	*Inches.*	*Inches.*	
Single lock, 30-foot span.	4	22	7	....	Standards.
	2	15	....	6	Transoms.
	4	15	....	4-6	Ledgers and shore transoms.
	4	20	....	3	Diagonal braces.
	1	15	....	10	Fork transoms.
	10	20	....	6	Balk.
	4	20	....	3-6	Side rails.
Double lock, 45-foot span.	4	20	7	....	Standards.
	2	15	....	6	Main transoms.
	4	15	....	4-6	Ledgers and shore transoms.
	2	25	....	8	Distance pieces.
	2	15	....	10	Road transoms.
	4	20	....	3	Braces.
	15	20	....	6	Balk.
	4	20	....	4-6	Side rails.

TABLE XXII.

59. **Rope** required for **spar bridges:**

Description and size of ropes.	Single lock.			Double lock.		
	Ropes.	Total length.	Maximum weight.	Ropes.	Total length.	Maximum weight.
	No.	*Feet.*	*Lbs.*	*No.*	*Feet.*	*Lbs.*
Foot ropes, 3-inch circumference, 40 to 60 feet	4	240	71	4	240	71
Guys, 3-inch circumference, 120 to 150 feet	8	1,200	356	8	1,200	356
2-inch circumference, 108 feet	2	216	29	2	216	29
1½-inch circumference, 54 feet, for transom lashings	4	216	29	8	512	68
1½-inch circumference, 36 feet, for ledger and brace lashings	10	360	27	14	504	37
1-inch circumference, 24 feet, for road bearers	10	210	7	10	210	7
Spun yarn	....	....	7	....	....	7
Aggregate length and weight of rope required	....	2,442	526	....	2,882	575

Miscellaneous materials: 2 pieces chalk; 8 pickets 5 feet long; 4 pickets 3 feet long; tracing pickets; plank for chess (1½ by 12 inches by 10 feet, according to span); rack sticks and lashings (at 4-foot intervals, according to span); 2 tracing tapes, 150 feet each.

60. **Roadway** of **spar bridge.**—For infantry in fours crowded the transoms should have a diameter of not less than 9 inches for a span of 15 feet. Five stringers 2 feet 3 inches c. to c., and 6 inches diameter at the tip will suffice. If the sticks vary in size, the larger ones should be notched down on the transom so as to bring the tops in the same plane. The stringers should be long enough to overlap the transoms and should be lashed together at each tip. The floor is held down by side rails over the outside stringers and lashed to them. If lumber can not be obtained, a floor may be made of small spars, the interstices filled with brush, and the whole covered with loam or clay (figs. 108 and 110).

61. **Trestle bridges.**—Applicable to shallow rivers with firm bottoms and not subject to sudden change in water level. Improvised structures are seldom satisfactory. On a rocky bottom they are difficult to fit, on a muddy bottom they sink, and on a sandy bottom they undermine. *Portable trestles* require but little timber and can easily be transported. The parts are fitted together and numbered to facilitate assembling. A trestle bridge is not limited as to length. The bays are of convenient length, usually 12 to 15 feet, depending upon the traffic and the available material.

Accurate soundings across the stream along both sides of the bridge are required where the bottom is irregular to determine the length of legs and the height of the cap of each trestle above the bottom.

62. **Trestles** of **spars** and **lashings** are applicable to rocky ravines or when circumstances make it difficult to drive piles. They *may be two, three,* or four legged.

The two-legged form is similar to a frame for a single-lock bridge (par. 55), the only difference being that the trestle standards have a greater slope. Four men should make the trestle in 45 minutes. If the timber be weak, both ledger and transom may be doubled, as in figure 103. Light material may be used for the diagonal braces, as little strain is brought upon them. Two-legged trestles are maintained in upright positions by lashing the stringers to the transoms and by longitudinal bracing of adjacent trestles. The trestles next the shore must be rigidly braced by spars lashed to the standards and to stout stakes driven in the bank. This *end bracing* is *very important.*

Three-legged trestles (fig. 111) have the advantage of utilizing light material. They will stand without bracing and admit of more ready adjustment than the other forms.

To make a tripod, the lashing of the tips may be done as described in paragraph 49 or as shown in figure 112, the latter method permitting a transom to be placed in the fork. In the latter method the tips of the two legs are lashed together with a shear lashing (par. 48), and the third leg or tripod is then added. The tripod is then raised, the feet placed on the angles of an equilateral triangle with sides about half the height of the tripod and secured by lashing three light ledgers, as shown in the figure.

Three-legged trestles of bamboo fitted with three transoms lashed at different heights for varying depths of water were used near Manila for a portable bridge 150 feet long. The floor was made of bamboo frames covered with bamboo mats. The floor for each bay was carried entire and was designed to be hung by ropes from the transoms. The entire bridge could be carried by 120 men, but was rather heavy for them.

A four-legged trestle made of spars and lashings is shown in figure 113. It consists of two frames similar to two-legged trestles, locked together at the transoms and connected by short ledgers at the feet. The breadth of the base on which the trestle stands should not be less than one-half the height. Figure 114 shows a four-legged trestle for same use as that shown in Fig. 113. It presents slightly different arrangements of the parts and of the lashings. Four-legged trestles are not convenient for use on uneven bottom.

If trestles are placed in considerable depth of water, it may be necessary to ballast them temporarily until the weight of the roadway can be put on. Pieces of rock or sacks of gravel may be used for ballast or any articles of the equipment in compact form and of considerable weight may be lashed to the trestle when it is set and removed to the next when no longer needed.

In setting trestles of all forms on dry foundations they may be made with legs of uniform length as prescribed in the text, set up in place, and fitted to the ground by lashing suitable extension pieces to the feet.

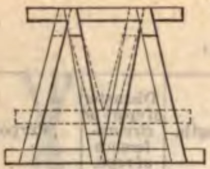


Fig.116

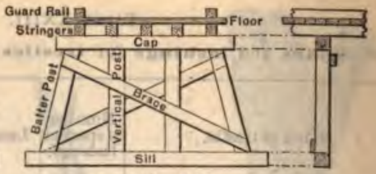


Fig.117

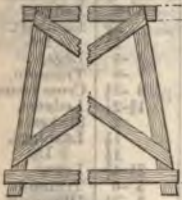


Fig.118

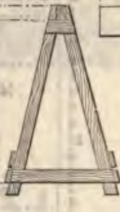


Fig.119

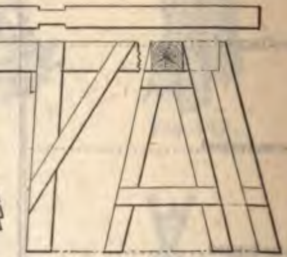


Fig.120

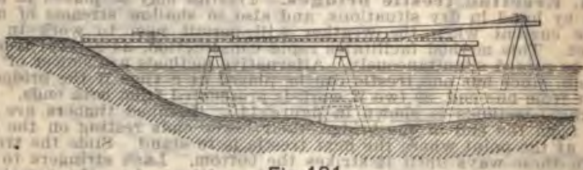


Fig.121

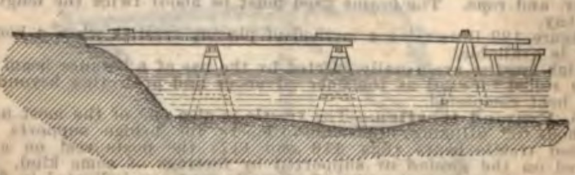


Fig.122

The simplest framed trestle is the sawhorse. The relative dimensions and arrangement of its parts are as shown in figures 118, 119, and 120. The figures and proportions given are to be regarded as typical only with the widest latitude of adaptation to materials available.

66. Figures 123 and 124 illustrate a trestle bridge designed to carry the loaded escort wagon with a factor of safety of 3. If the height of the trestle is not greater than its width, the bracing shown in figure 125 may be used. It has the advantage of giving a middle support to the transom. Figures 126 and 127 show a hasty trestle bridge thrown across Conemaugh River at Johnstown, Pa., by a detachment of engineers, June, 1889. The piers are *stiffened laterally* by planking the uprights on both sides for some distance above the bottom, and are made *self-anchoring* by filling the 6-inch space between the planks with scrap iron or other heavy material.

Trestles of considerable height may be made in two or more tiers, the cap of each forming the sill of the one next above and resting upon it, or the posts may be continuous (figs. 128, 129, and 130).

When trestle sills are supported on footings or piles, the points of support must be under the posts.

67. **Pile bents** are similar in construction to trestle bents. The sill is omitted, the posts are driven into the ground, and usually are all vertical. Pile bents are to be preferred on soft ground and in rapid streams. Piles should be from 8 to 12 inches in diameter at the butt for highway traffic, and must be approximately straight, or they can not be driven. Dimension timbers, the nearer square the better, make excellent piles.

Types of arrangement of piling for railroad work are shown in figures 132 to 136.

For bents more than 10 feet high, the outside piles may be driven with a batter. Bents 10 to 20 feet in height have one set of *sway braces*. Crossed diagonals of 3 by 10 inch plank, one on each side of the bent, suffice (fig. 140). Heights of more than 20 feet should have additional sets of crossed diagonals, with horizontal sticks between them (fig. 142).

Except in streams subject to floods, *longitudinal bracing* also is required. It may be in one or more tiers, as described for sway bracing, or as is shown in figure 129.

A pile bent for water 10 feet deep is shown in figure 137. Figures 138 and 139 show a bridge built across the Portuges River, P. R., and designed to allow *floods to pass over* it without other injury than carrying away the hand rail, which is lightly constructed with that end in view. Figures 140 and 141 show a type of pile bridge of which several were built in the Philippines.

68. **Pile driving.**—Piles may be driven with a hammer in mud or any loose soil except sand. In still water or moderate currents, and to the penetration usually sufficient for light work, piles may be driven with sledges or mauls. It is best done from a platform attached to the pile and going down with it, as shown in figure 143. The weights of drivers balance, and after the pile is well fixed in place the shore ends of the spars may be held shoulder high and lowered as the pile goes down, so as to keep the platform horizontal for the hard driving.

Heavier blows can be struck by the device shown in figure 143*a*. For four men the hammer may weigh 250 to 300 pounds.

For sand, a force pump and water jet are required, and these will often facilitate driving in other soils. For driving with the jet a length of hose and a piece of wrought-iron pipe, long enough to reach from the point of the pile to a point above the water level when driven, are required. After the pile is hoisted into the leads, attach the pipe to one side, its lower end opposite the point, which should *not be sharpened*, using two or three wrought-iron spikes driven a *short distance* into the wood and bent over the pipe. Place the pile in position, lower the hammer onto the head, couple the hose to the pipe

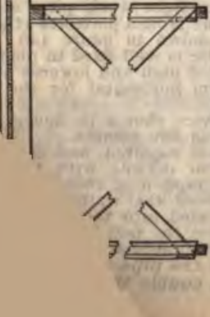


Fig. 123.

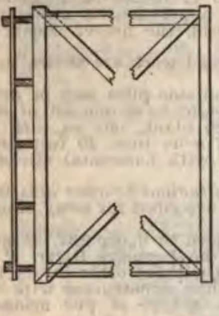


Fig. 124.

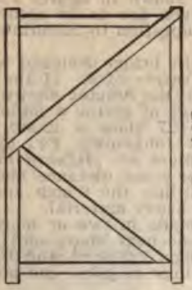


Fig. 125.

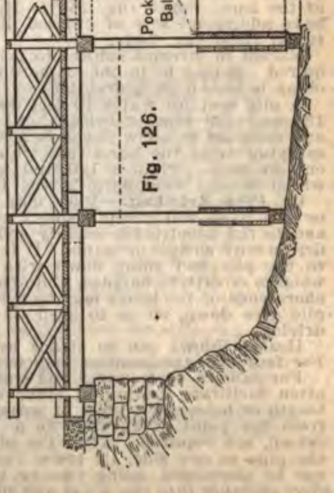


Fig. 126.

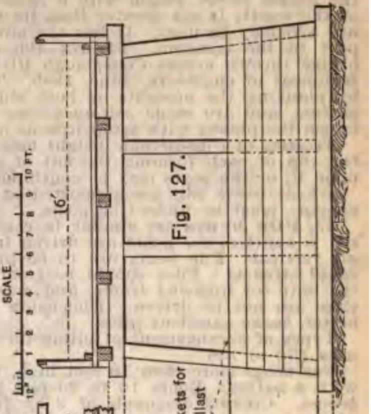


Fig. 127.

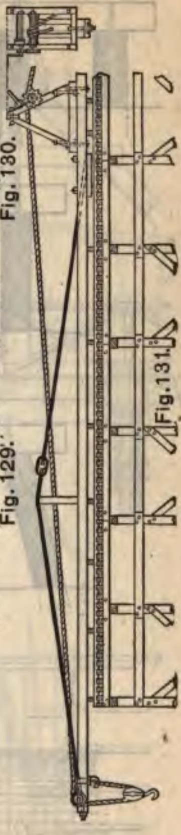


Fig. 131.

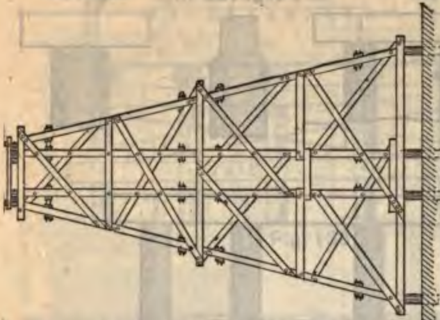


Fig. 130.

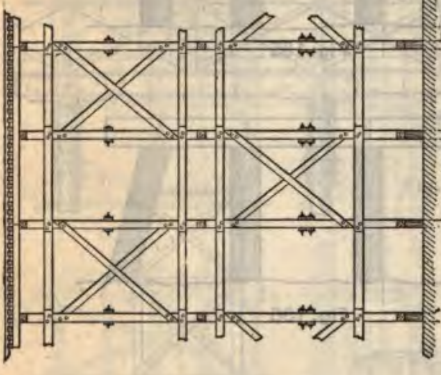


Fig. 129.

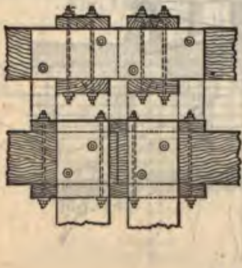


Fig. 128.

Fig. 132

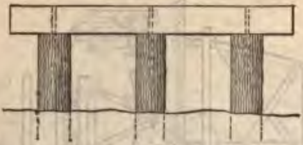


Fig. 133

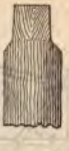
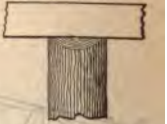


Fig. 134



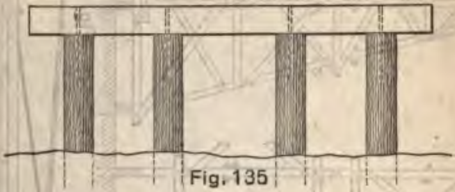


Fig. 135

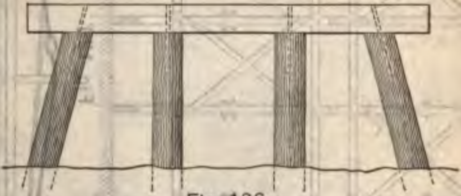


Fig. 136

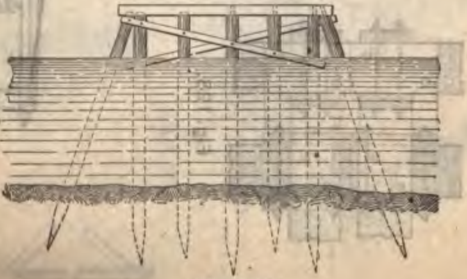


Fig. 137

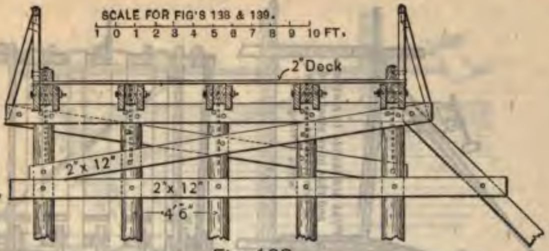


Fig. 138

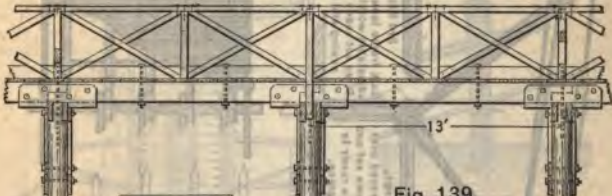


Fig. 139

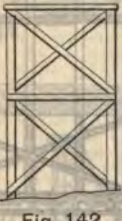


Fig. 142

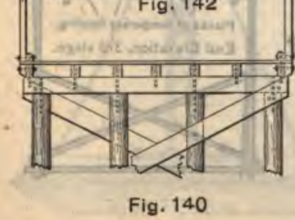


Fig. 140

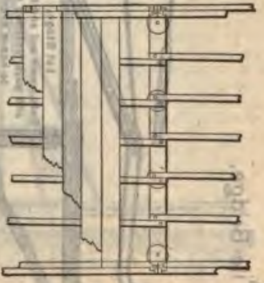
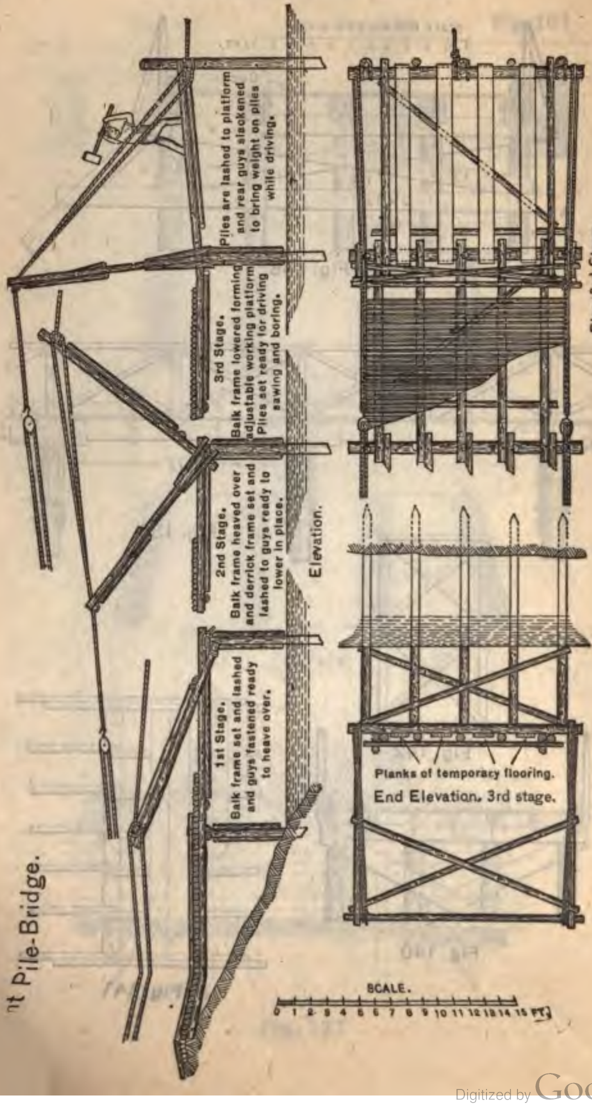


Fig. 141


Piles are lashed to platform and rear guys slackened to bring weight on piles while driving.
3rd Stage.
Balk frame lowered forming adjustable working platform Piles set ready for driving sawing and boring.
2nd Stage.
Balk frame heaved over and derrick frame set and lashed to guys ready to lower in place.
1st Stage.
Balk frame set and lashed and guys fastened ready to heave over.
Elevation.
Plan 3rd Stage.
Planks of temporary flooring.
End Elevation, 3rd stage.
SCALE.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 FT.

nt Pile-Bridge.

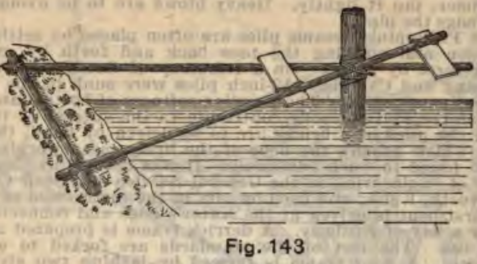


Fig. 143

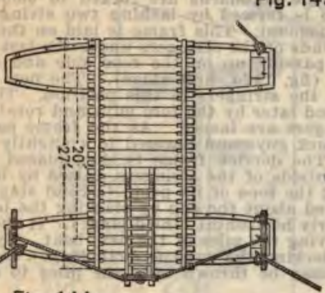


Fig. 144

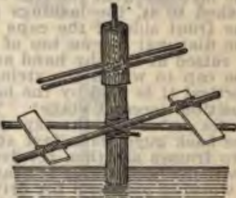


Fig. 143A

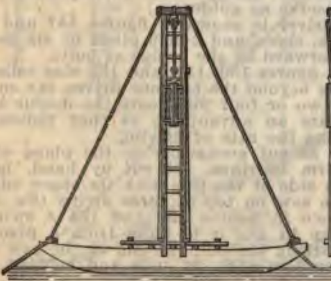


Fig. 145

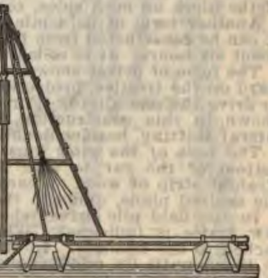


Fig. 146

and start the pump. If the pile does not settle under the weight of the hammer, tap it lightly. Heavy blows are to be avoided, as they will dislodge the pipe.

In the Philippine streams piles are often placed by setting them up in position and working the tops back and forth by guy lines or twisting them by levers. On a tributary of Camilleis River between Bayambang and Camilleis, 12-inch piles were sunk in the river to 10 or 12 foot penetration. The peculiar softness of bottom and the great weight of the native woods contribute to the success of this method.

When the piles of a bridge are to be driven by hand, the following method, which utilizes the floor of the bridge as a working platform, has been found to work admirably. It was devised by Capt. Rees, instructor of engineering in the General Service and Staff College, Fort Leavenworth, Kans., and used by him in the instruction of his classes.

The first bent is driven at the water's edge and connected with the shore by a bay of roadway. A derrick frame is prepared as shown in figure 142*a*. The feet of the standards are forked to embrace the trestle cap. A floor frame is formed by lashing two stringers to a trestle cap and placing a diagonal. This frame is laid on the floor of the last bay with the free ends of the stringers under the last cap and lashed to it, the lashings passing up on the rear side and down on the front side of the caps (fig. 142*a*, first stage). The new cap and the diagonal are on top of the stringers in this position. The frame is raised at first by hand and later by the fore guys and rotates about the cap to which the stringers are lashed. As the frame passes the vertical it is held by the back guys and lowered to a slightly inclined position (second stage). The derrick frame is then placed with its claws embracing the cap outside of the stringers, raised by hand and the back guys made fast at the tops of its posts (second stage). The two frames are then revolved about the cap by slacking the back guys until the floor frame is nearly horizontal (third stage). It then forms a working platform for driving the piles of the next bent. By lashing the cap to the piles and slacking the guys (fourth stage) the weight of the platform and men may be thrown onto the piles to assist in sinking them.

69. **Designs for pile drivers.**—If two service pistons with balk and chess are available a floating hand pile driver, shown in figures 144, 145, and 146, may be improvised. The construction is obvious from the drawings. The hammer is a log of heavy wood 16 inches in diameter and 4 or 5 feet long, flattened on opposite sides to fit loosely between the leads. Pairs of pins are inserted near the top and bottom of the block on both sides, to serve as guides.

Another form of field pile driver is shown in figures 147 and 148. It can be constructed from balk, chess, and 2-inch plank by six men in about six hours. It is rolled forward on the bridge as built.

The form of driver shown in figures 150, 151, and 152 also rolls forward on the trestles, projecting beyond the last one driven far enough to drive the one ahead. For two or four pile bents the double leads, shown in this construction, are an advantage, as they reduce the lateral shifting, besides doubling the rate of driving.

The *tops of the piles* must be cut accurately to the plane of the bottom of the car to give firm bearings. If cut by hand, nail a straight strip of wood on each side of the pile with its upper edge in the desired plane, and run the saw on top of these strips (fig. 149).

In the field pile driver shown in figures 150 and 151 a swinging saw frame is indicated. When in use it is hung from a pivot attached to the hammer. In starting the cut, the sag of the saw must be lifted until its middle is on line with its ends and held so until engaged in the cut.

70. **Operating field driver** (figs. 150, 151, and 152).—A bent just completed, overhaul the shifting tackles and attach them by straps to the last cap; fasten blocks to the caps on the outside of ills of the machine to serve as guides; slush or soap the run-
and haul away on the shifting tackles to advance the machine

Improvised Hand-Power Pile-Driver.

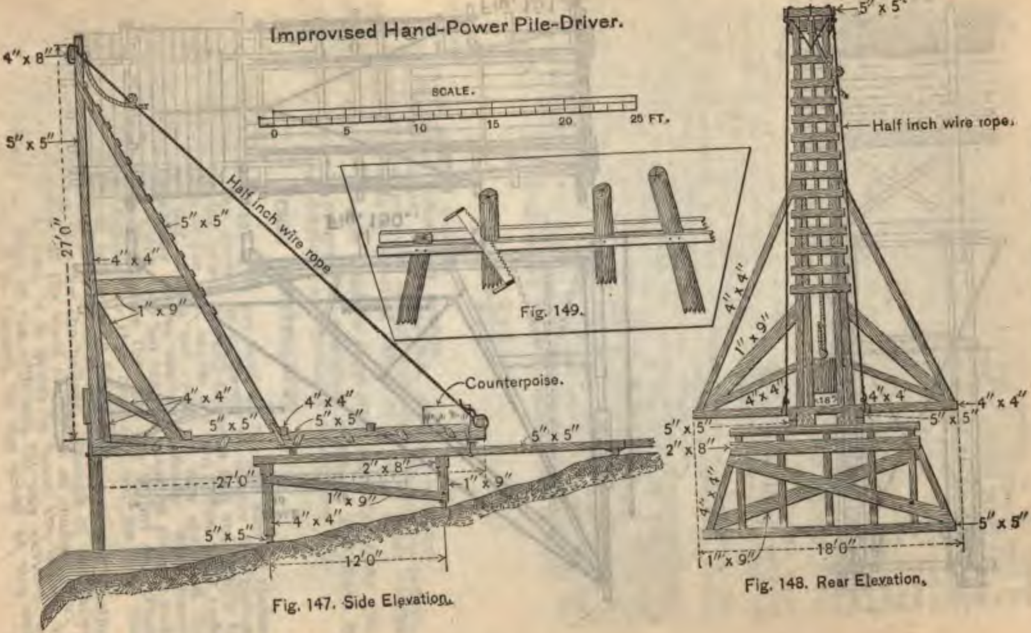


Fig. 147. Side Elevation.

Fig. 148. Rear Elevation.

Fig. 149.

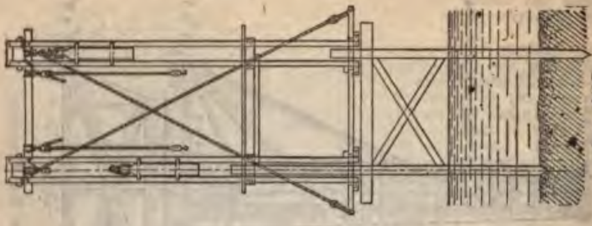


Fig. 152.

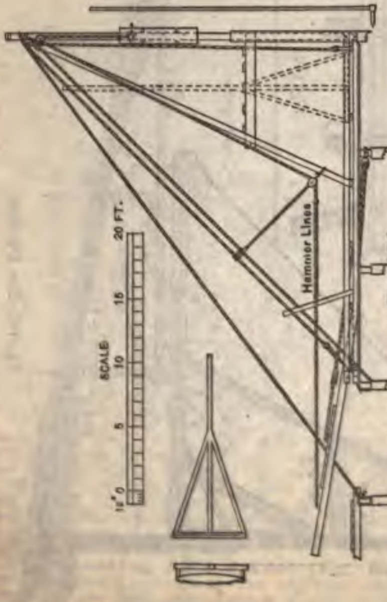


Fig. 150.

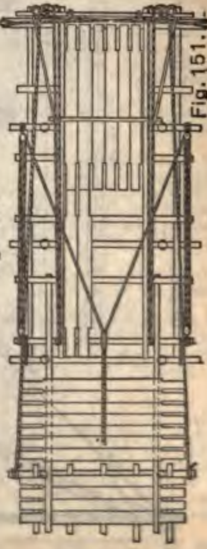


Fig. 151.

the proper distance. Lash the heel of the machine to the trestle cap. As soon as the leads clear the last cap the hammers may be lowered into the water to take off their weight. When made fast in the new position, haul hammers to the top of leads; hook onto piles with the hoisting tackles and swing them in place; pass lashings to hold them and lower the hammers to rest on their tops. Hoist and drop the hammers until the piles are driven to the required penetration or resistance. Hoist the hammers, hang the saw frame, and adjust to proper height. While sawing off, hook onto a cap with hoisting tackles, sling it horizontally into position, and onto the piles as soon as sawed. Bore through the cap into piles and drive driftbolts or treenails. Spike on the longitudinal braces that stay this bent against the pull of the shifting tackles and advance to the next bent. Other bracing may be placed after the pile driver has passed.

Above applies to bents with two piles. For driving four-pile bents the machine is shifted laterally on cross skids with tackle or with handspikes. When mules are available they may replace the men on the hammer lines to great advantage.

71. The **supporting power** of **piles** is not of paramount importance in military bridges of hasty or temporary character, since a slight settlement is usally of no especial consequence.

It may be said in general that the bearing power of piles will vary from 5 to 70 tons according to the size of the stick, its penetration, and the character of the soil into which it is driven. A frictional resistance per square feet of the surface of the pile in contact with the soil may have working limits of 200 to 800 pounds. The smaller should not be exceeded in alluvial and soft soil nor the greater in firmer material such as stiff clay, sand and gravel, or mixed material.

If it is necessary to insure against settlement, the following formula, known as the "Engineering News Formula," may be used:

$$L=\frac{2\,wh}{S+1}$$

in which

L=safe load in pounds.
w=weight of hammer in pounds.
h=fall of hammer in feet (average of last few blows).
S=penetration per blow in inches (average of last few blows).

This formula includes a factor of safety of 6, or is based on the assumption that $\frac{12\,wh}{S+1}$=the ultimate supporting capacity of the pile.

No pile formula yet proposed is absolutely reliable. The above is one of the latest and simplest, and probably among the best.

CRIB CONSTRUCTION.

72. In *dry situations* the cribs are built on the site and no fastenings are required. The ground is prepared to receive the bottom timbers, level and bearing firmly toward the ends and but lightly in the middle. The sticks of the next course are laid across their ends, noting that they rest fair and do not rock. If logs are used, the ends are flattened sufficiently to give bearing surfaces. With dimension timbers each piece which does not lay fair must be given a solid bearing by shims or wedges before the next one is put on. These small pieces must be fastened so that they can not jar out. The construction of a dry crib is shown in figure 153.

The part of a crib that is to stand *in water* must be tied together and adapted to form a cage for the ballast. Enough of the ballast to overcome the flotation of the wood should be so confined that it can not escape. For the rest, it is better to leave the ballast free to run out through the floor of the crib and fill any cavities in the bottom which may exist or be formed by the scour of the current.

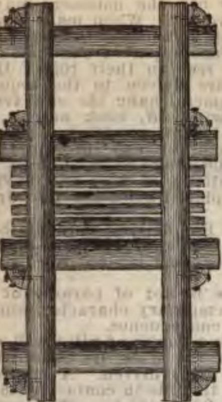


Fig. 155

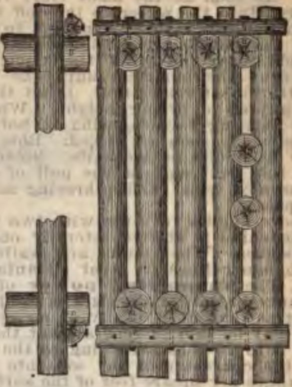


Fig. 156

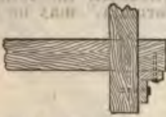


Fig. 157

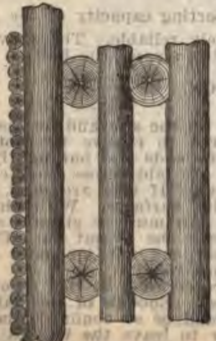


Fig. 153

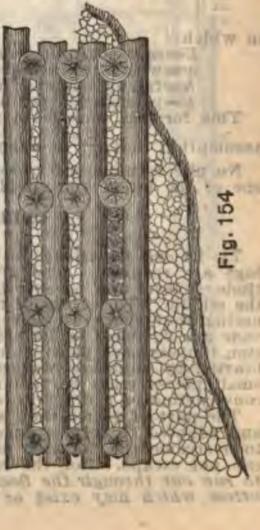


Fig. 154

A crib may be given a level bearing on a rough or sloping bottom by holding it in the desired position and throwing in ballast which runs through.

A large crib may be made in compartments or pockets, the interior ones floored to take the sinking ballast and the others open at the bottom to allow ballast to run through (figs. 154 and 155). A small crib made in one pocket may have extra logs in the second course on which a large rock can be laid to sink the crib, after which smaller ballast may be thrown in around it (fig. 156).

73. Cribs are built on shore usually on inclined ways, and when up to a sufficient height to form a substantial raft may be launched. They are built up to a little more than the depth of the water in which they are to stand and are floated to their places. The sinking ballast is then placed in the closed compartments or on the floor prepared to receive it, until the crib is well grounded. By means of spars set at the corners with tackle attached, the lower corners may be raised until the crib is level, and the rest of the ballast thrown in.

The construction of the *sides* of a crib must be *adapted* to the *ballast* to be used. If large stones are available, the full interval may be left between sticks as described for dry cribs. If the ballast is small, the timbers must be gained together to make the spaces smaller, and it may even be necessary to plank the sides of the crib.

74. To resist the *outward thrust* of the *ballast* the logs may project in full size a foot or two at each end, so that each one rests in a notch cut in the one below. A log may be split into quarters and one of these placed in each outside corner, nailed or pinned to each timber. For light cribs in shoal water the projection may be small and a pole substituted for the quarter log. Both of these methods are shown in figures 155 and 156. For cribs of squared timbers, two planks nailed or pinned in the outside corner, as shown in figure 157, are best.

75. On a bottom of *soft mud* it may be necessary to *distribute* the *weight* of the pier over a greater area than its own bottom. For this purpose riprap stone is commonly used if easily procurable. A quantity is thrown in on the site of the crib and allowed to find its bed. When the bottom is well covered and no further settlement appears, the top is roughly leveled and the pier sunk on top of the mound.

If stone can not be had, a raft of logs may be sunk on the bottom and the pier built on that. The logs should run parallel to the short side of the crib or pier (figs. 162 and 163).

76. A pier placed in *running water* increases the tendency to *scour* in its vicinity, and if the bottom is erosible may be undermined. To prevent this, a flexible construction of brush, called a mattress, may be used. Its construction and use are illustrated in figures 158–161.

A grillage of poles is made on the ground or on skids, and at every intersection a stake is set somewhat longer than the desired thickness of mattress. A double lashing is attached to the grillage at each stake, brought to the top of the stake, and loosely fastened with plenty of end.

Brush is now laid on in one or more tiers until the desired thickness is obtained. A second grillage is laid on the top with its intersections at the stakes. The lashings are removed from the stakes, passed around the upper grillage, and set up with levers and rack sticks (fig. 160). Such mattresses are usually built 1 to 2 feet in thickness.

The mattress is launched and floated to its place, where it is sunk on the bottom by throwing on rock or other ballast. When in place the crib or pier is built on top of it.

The effect of a mattress is shown in figure 161. As the current *scours under its outer edge* the mattress bends downward, following *the bottom until* the scour ceases. The mattress must be larg *enough so that* this action at the edges will not disturb the middle.

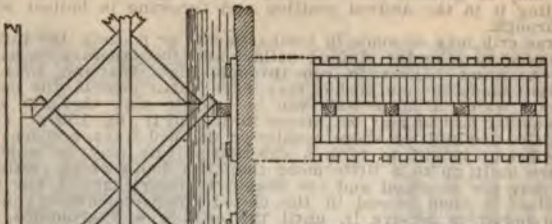


Fig. 163.

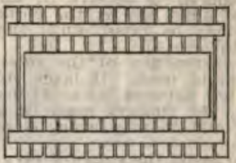


Fig. 162.

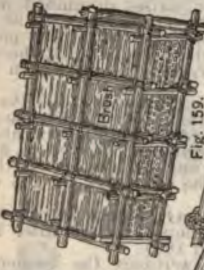


Fig. 159.

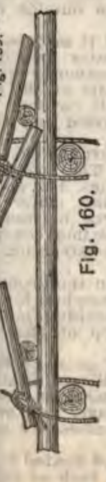


Fig. 160.

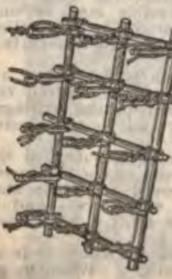


Fig. 158.

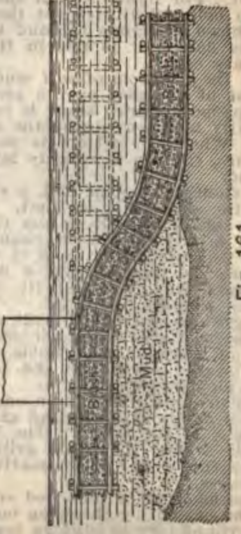


Fig. 161.

LANDING PIERS.

77. The dispositions described for pile and crib bridges are those usually adopted for temporary piers, wharves, or docks for loading or discharging vessels. The chief difference is in the provision made against *lateral thrusts,* which are much greater than in the case of bridges. Vessels warping and out and even striking the pier, which can not be avoided, cause excessive lateral strains which call for special features in addition to much heavier construction throughout.

Lighters can be discharged at a properly constructed dock in considerable seaway. Transports can also be discharged in a moderate seaway by providing adequate mooring devices at bow, stern, and on the outside, so that the vessel can be held alongside of the pier, but not touching it. Only in perfectly protected situations can a large ship lie directly against a pier.

78. The **best mooring** is a massive structure of piles driven close together and connected near their tops by a cable, or by bolts, or both. Such a construction is often called a *dolphin.* It yields readily to the first impact and develops resistance steadily but rapidly. Figure 164 shows the usual construction, and figure 165 the method of binding with wire rope. The end of the rope is stapled to a pile and the rope drawn around the dolphin until it bears on the next one. A strain is then put on with a tackle and a staple or spike driven in the second pile and so on. At least three or four complete turns should be taken. Wire rope is best; chain next.

79. Such dolphins require heavy plant for their construction. If materials are abundant, a crib mooring may be made with ordinary tools. The crib should be square, with a side not less than the depth of water at low tide. It should be exceptionally well fastened. It should be constructed with a middle pocket, to be kept free from ballast until the crib is sunk and a cluster of piles has been put down through the pocket and driven into the bottom as far as possible. The tops of the piles should be arranged like the dolphin. Ballast, preferably of moderate size, will now be thrown into the middle pocket and packed closely around the piles to support them. Such a mooring is less elastic than the dolphin and will be more destructive of lines and of fastenings on the ship, but it can be made when a dolphin of sufficient strength can not.

80. Figures 167 to 170 illustrate points which must receive especial attention in building pile docks. These are the arrangement of fender piles and chocks so that vessels may ride up and down against the dock without catching, the inclined or spur piles driven to resist lateral thrusts, and the arrangement of fastenings on the dock to take heavy strains.

FLOATING BRIDGES.

81. Bridges of this class have several disadvantages, due to change in grade of roadway with change of water level and with change of load, and to their limited capacity, which can not exceed the flotation of the supports. As a rule, such bridges will be resorted to only when the materials for them are plentiful and the materials for other kinds scarce.

This rule finds an important exception in the organized bridge equipage prepared in advance to be carried with an army. Such a bridge possesses a great advantage in the paramount element of time, since it can be laid, crossed and taken up in less time than any other form of bridge can be built, and its component parts can be used as water transportation for several important purposes which no other kind of bridge can subserve.

82. The bridge equipage adopted for the United States service is of two forms, *heavy* and *light.* The heavy equipage is sufficient in capacity for all requirements of an army on the march and is mobile

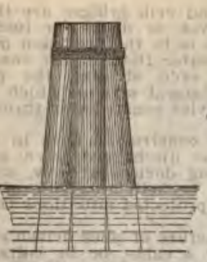


Fig. 164

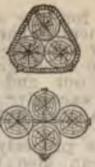


Fig. 166

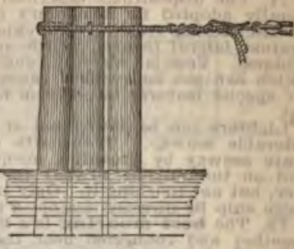


Fig. 165

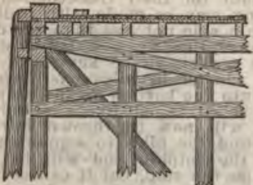


Fig. 167

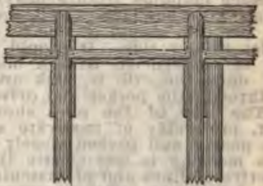


Fig. 168

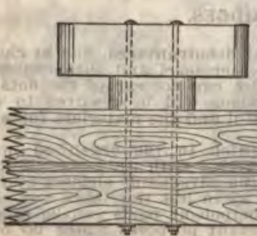


Fig. 169

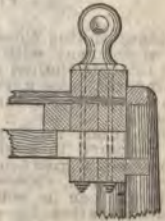


Fig. 170

enough to be carried at the ordinary rate of marching. In the light equipage, capacity is somewhat sacrificed for the sake of further mobility to enable a bridge to be carried with a rapidly moving column.

The trains of the heavy equipage are composed of six pontoon divisions and one supply division.

The trains of the light equipage are composed of three pontoon divisions. The pontoon section of the engineer train of an Infantry division contains two heavy pontoon divisions and one-third of a pontoon supply division. The pontoon section of the engineer train of a Cavalry division contains three light pontoon divisions.

The principal parts in both forms of bridge are *pontoons* or boats; the longitudinal bearers or stringers joining them, called *balks;* the cross planks, called *chess;* and the beams which hold the chess in position, called *side rails* (fig. 181).

83. In the heavy train each division will construct a bridge of 11 bays, or 225 feet in length, and is divided into four *sections,* two of which are called *pontoon sections* and the other two *abutment sections.* The two abutment or end sections suffice for any length of bridge. Increase in length is accomplished by adding one or more ponton or interior sections. The pontoon section is never divided, as it can not be done without breaking wagon loads. This equipage weighs, wagons included, 315 pounds per foot of bridge, or without wagons 169 pounds.

A division of light equipage will construct 186 feet of bridge. It is not divided into sections, as each pontoon wagon carries the material for a complete bay and the bridge may be lengthened by adding one or more pontoon wagons. This equipage weighs, including wagons, 275 pounds per foot of bridge, or without wagons 128 pounds.

84. **Heavy equipage.**—A division is loaded on 16 wagons. Eight of them are called *pontoon wagons* and carry each a pontoon, 7 long balks, anchor, cable, 5 oars, 2 boat hooks, 20 lashings, 6 rack sticks, 2 scoops, ax, hatchet, bucket, and 20 pounds spun yarn. Four of the wagons carry chess or floor planks only, 60 each, or enough for 3 bays, and are called *chess wagons.* Two wagons carry each a complete trestle, 7 long balks, 7 trestle balks, 2 abutment sills, and 2 coils of rope. The *tool wagon* carries axes, shovels, picks, tools and materials for carpentry, saddlery, calking and painting, and space cordage. The *forge wagon* carries a forge, smithing tools, iron, and other materials. Each wagon is drawn by 6 mules with 1 driver.

85. **Supporting power of boats.**—The boats of the heavy train are of wood, of about 9½ tons gross displacement, and weigh 1,600 pounds. Each can carry 40 infantrymen armed and fully equipped besides its crew, a total of about 9,300 pounds. This load crowds the boat and should be used only in favorable conditions. Thirty infantrymen and crew is normal load for one boat. In rough water or swift currents 20 men and the crew make a suitable load. The ponton is cranky, and uneven loading and shifting of loads must be avoided.

The light or canvas ponton is of 7½ tons gross displacement and weighs 580 pounds. Its normal load is 20 men and crew, which should be reduced for unfavorable conditions.

86. The **supporting power** of the **bridge** is determined by that of the roadway, purposely made less than that of the pontons. With a factor of safety of 4, the safe uniform load of the standard heavy bridge of 5 balks is 9,500 pounds on the 14 feet 4 inches between the supports, or 660 pounds per linear foot. This is more than the weight of infantry armed and equipped in column of fours, but less than the weight of such a column if crowded by a check. The corresponding concentrated center load is 4,750 pounds, which is about that on one axle of a wagon of 5 tons gross weight. It is more than the field gun and carriage and 1,675 pounds less than the siege gun. Each additional balk above 5 adds 165 pounds per foot to the safe uniform load, or 1,280 pounds to safe concentrated load. Seven balks will carry the siege gun with a factor of safety of nearly 4.

Six extra balks, or 11 in all, will carry as much concentrated load as the boats will support. Extra balks when used should be added in pairs and concentrated under the wheel tracks.

When either end of a bay is supported at one point only, as on an abutment or saddle sill, 30 per cent more balks must be used for the same load and span. If both ends are so supported, 50 per cent more balks will be required for the same load and span.

The above loadings should not be exceeded except under unusual circumstances and with great caution. With new and perfectly sound material in an emergency of actual service an officer in charge of a bridge would be justified in doubling the loads given, or, in other words, reducing the factor of safety to 2.

Heavy loads on wheels may be partially distributed by track planks or by skidding the wagons over on shoes or runners. For long continued use a false floor of common lumber should be laid to take the wear off the chess. Such a floor serves also to partially distribute the load. A covering of hay or straw is advantageous.

The *floor system* of the *light train* has nine-tenths the strength of the heavy, with equal number of balks for concentrated loads and equal capacity per linear foot for uniform loads, as the bays are shorter. The standard floor of 5 balks will carry as much as the boats will safely support.

87. Capacity ponton bridges.—Bridges marked "X" will safely carry load indicated.

TABLE XXIV.

CAPACITY HEAVY EQUIPAGE BRIDGE.

Clear span in this table refers to distance between gunwales of adjacent boats.

Load.	Extended interval balk per bay (clear spans, 19 feet 7 inches).			Normal interval balk per bay (clear span, 14 feet 4 inches).			Reduced interval balk per bay.			
							Span, 10 feet 4 inches.		Span, 7 feet.	
	5	7	9	5	7	9	5	7	5	7
4-mule Army wagon	×	×	×	×	×	×	×	×	×	×
6-mule Army wagon	....	×	×	×	×	×	×	×	×	×
3-inch gun	×	×	×	×	×	×	×	×	×	×
3-inch caisson	×	×	×	×	×	×	×	×	×	×
4.7-inch gun	....	....	....	....	×	×	×	×	×	×
6-inch howitzer	....	....	....	....	×	×	×	×	×	×
7.6-inch howitzer	....	....	....	....	....	×	....	×	×	×
9.5-inch howitzer	....	....	....	....	....	....	....	....	....	×
12-inch howitzer	....	....	....	....	....	....	....	....	....	....
1½-ton truck (loaded)	....	....	....	....	×	×	×	×	×	×
(Packard) (empty)	....	×	×	×	×	×	×	×	×	×
3-ton truck (loaded)	....	....	....	....	....	....	....	....	....	×
(Peerless) (empty)	....	....	....	....	×	×	×	×	×	×

idge with spans of 7 feet may be built by placing an extra boat *idle of each bay of* bridge built with extended intervals.

Bridge with 10 feet 4 inches clear spans (16 feet c. to c. of boats) requires 4 feet of the set of balks in each bay to overhang beyond the gunwale of one boat. Improvised means must be adopted to secure the boat in place in the bridge when the balks overhang.

To provide a bridge with clear spans of 10 feet 4 inches per bay of the same length as one built with normal interval, the material used for the latter must be increased by three ponton wagons and one chess wagon or equivalent. To provide a bridge with clear spans of 7 feet per bay having the same length as the one built with normal intervals, the material used for the latter must be increased by seven ponton wagons and two chess wagons or equivalent.

TABLE XXV.

CAPACITY LIGHT EQUIPAGE BRIDGE.

	Normal interval balk per bay (clear span, 10 feet 2 inches).	
	5	7
4-mule Army wagon	×	×
6-mule Army wagon	×	×
3-inch gun	×	×
3-inch caisson	×	×
4.7-inch gun	....	×
6-inch howitzer	....	×
7.6-inch howitzer	....	....
9.5-inch howitzer	....	....
12-inch howitzer	....	....
1½-ton truck (loaded)	....	×
Packard (empty)	×	×
3-ton truck (loaded)	....	....
Peerless (empty)	....	×

The bridge of light equipage with normal interval will carry the maximum load allowed on the canvas boat. Therefore the bridge capacity is not increased by reducing intervals.

The loads of the 12-inch howitzer and the 75-horsepower caterpillar tractor are greater than the net buoyancy of either the canvas boat of the light equipage or the wooden boat of the heavy equipage. Therefore no bridge can be built of the ponton equipage to pass them without means of increasing the buoyancy of the boats. The load of the 45-horsepower caterpillar tractor is so close to the net buoyancy of the wooden boat of the heavy equipage that under ordinary conditions it is inadvisable to attempt to pass it over any bridge of light or heavy equipage. In an emergency under very favorable conditions it might be possible to pass this load over an 11-balk bridge of heavy equipage with clear span of 7 feet, but the Engineer officer in charge is responsible and should carefully investigate all conditions and estimate effects before deciding to authorize its passage.

As the equipage of a ponton division (heavy or light) provide only sufficient number of balks to construct a bridge of five balks per bay, when all the supports (boats and trestles) are used, additional balks must be obtained to construct a bridge having more than five balks per bay; or the number of bays possible of construction will be reduced to an extent necessary to provide additional balks.

In passing the heavy loads such as the howitzers (6-inch or larger) or the loaded motor trucks officers in charge of bridges should carefully investigate the span of the chess as they lie upon the balks, to provide that the spans where the wheels of the vehicles track shall not be too great to support the load to be carried. Laying longitudinal plank to form wheel tracks, each track made up of three rows of plank approximately 2 by 10 inches, will be found useful in distributing the load and will save wear on chess.

In passing heavy loads an interval of two bays between successive loads may be found advisable so that when a load is over any boat part of the load may be transmitted to adjacent boats.

All motor vehicles except passenger vehicles should be required to cross the bridge at less than 4 miles per hour, unless experience in a particular case indicates a higher rate of travel practicable and the situation requires the increased speed.

There will occur cases when the Engineer officer in charge of a ponton bridge could permit some of the loads to cross his bridge which are represented in the table as not safe to carry. The condition should be very favorable, and the Engineer officer in reaching a decision must assume responsibility. For example, the table does not indicate that the empty 3-ton truck can be safely carried over a five-balk bridge of heavy equipage built with normal intervals, yet the empty 3-ton truck was safely passed over a bridge of this type at Eagle Pass, Tex., in 1916.

88. **Displacement of ponton boats.**—The following displacement tables of heavy and light boats of the ponton equipage will be found useful in estimating the effect on boats in a bridge of known loads passing over a bridge:

TABLE XXVI.

DISPLACEMENT OF HEAVY PONTON BOAT.

Draft.	Water displaced.	Draft.	Water displaced.
Inches.	*Pounds.*	*Inches.*	*Pounds.*
1	350	17	9,475
2	675	18	10,125
3	1,025	19	10,800
4	1,500	20	11,500
5	1,975	21	12,250
6	2,500	22	13,000
7	3,025	23	13,750
8	3,600	24	14,550
9	4,200	25	15,350
10	4,850	26	16,150
11	5,500	27	16,950
12	6,150	28	17,750
13	6,825	29	18,625
14	7,500	30	19,500
15	8,150	31	20,400
16	8,825	32	21,280

	Pounds.
Weight of pontoon boat (approximately)	1,600
Dead weight of bridge (normal interval 5 balks per bay) on 1 boat (approximately)	1,900
Displacement of boat in bridge	3,500
t available buoyancy of a boat (allowing 4 inches free-ard) (approximately)	14,250

TABLE XXVII.

DISPLACEMENT OF LIGHT (CANVAS) BOAT.

Draft.	Water displaced.	Draft.	Water displaced.
Inches.	*Pounds.*	*Inches.*	*Pounds.*
2	1,025	16	8,475
4	2,050	18	9,600
6	3,100	20	10,725
8	4,150	22	11,850
10	5,200	24	13,025
12	6,300	26	14,200
14	7,375	28	15,350

	Pounds.
Weight of pontoon boat (approximately)	580
Dead weight of bridge (normal interval 5 balks per bay) on 1 boat (approximately)	1,150
Displacement of boat in bridge	2,730
Net available buoyancy of a boat (allowing 4 inches of freeboard (approximately)	10,295

Experience on the Mexican border in 1916 indicated that the 4.7-inch gun crossing a normal interval light equipage bridge having 7 balks per bay displaced the canvas boats 12 inches; that the 1½-ton truck loaded or the 3-ton truck empty would displace the boats 9 inches in a normal interval heavy equipage bridge having 5 balks per day.

TABLE XXVIII.

89. **Names and dimensions** of the principal **parts** of the **light** and **heavy trains:**

Name of part.	Light train.	Heavy train.
Pontoon 9½ tons		31 feet by 5 feet 8 inches by 2 feet 7 inches.
Canvas pontons, 6 tons	21 feet by 5 feet 4 inches by 2 feet 4 inches.	
Balks and side rails	22 feet by 4½ by 4½ inches.	27 feet by 5 by 5 inches.
Trestle balks		21 feet 8 inches by 5 by 5 inches.
Chess	11 feet by 12 by 1½ inches.	13 feet by 12 by 1½ inches.
Abutment sills		14 feet by 8 by 6 inches.
Trestle caps, 2 planks, each		20 feet by 12 by 2 inches.
Trestle legs		15 feet by 7 by 3½ inches.
Trestle shoe		
Suspension chains		½ inch by 8 feet.
Paddles	8 feet.	
Oars		18 feet.
Boat hooks	8 feet, blunted points.	10 feet.
Rack sticks	1¼ inches diameter, 2 feet long.	1¼ inches diameter, 2 feet long.
Anchor	75 pounds.	150 pounds.
Anchor cable	3 inches circumference, 180 feet long.	3 inches circumference, 240 feet long.
Lashings	1 inch circumference, 18 feet long.	1 inch circumference, 18 feet long.
Canvas-pontoon cover	No. 0000 cotton duck	
Pontoon chest	8 feet long, 2 feet 4 inches wide, 18 inches deep.	

TABLE XXIX.

90. **Weights of wagons and their loads:**

Kind of wagon.	Light train.			Heavy train.		
	Wagon.	Load.	Total.	Wagon	Total.	Total.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Ponton	1,750	1,985	3,735	2,200	2,900	5,100
Chess	1,750	1,856	3,606	1,750	1,280	4,030
Trestle	1,750	2,060	3,810	2,200	2,635	4,835
Tool	1,700	1,938	3,638	1,700	2,100	3,800
Battery and forge	2,081	600	2,681	2,081	600	2,681

91. **Boat bridges.**—When it becomes necessary to use boats found on the stream or elsewhere, select those as nearly of one size as possible. Of these, use the largest for the shore ends and for the swiftest currents. Estimate their supporting power roughly by comparing their size with the ponton boat, heavy or light, or compute as in paragraph 93. Support the balks on saddle sills and transoms blocked up from the frames of the boats. If boats differing very much in displacement are used, make the bays supported by the small boats shorter than those supported by the larger ones. Avoid getting a very large and a very small boat adjacent. The floor system may be designed as in paragraph 60 for spar bridge. With scow-built barges, which will usually have excess of supporting power, a serviceable bridge is readily built. If the boats are large and well decked, they may be placed endwise in the bridge, separated by 20 feet or more, the intervals spanned by bays of roadway and the decks used for roadway on the boats themselves. With boats of different shapes and sizes, such a bridge should be attempted with great caution, and only under exceptional circumstances.

92. **Barrel piers.**—When barrels are available, floating piers can be made by assembling a sufficient number of them by means of timbers or lashings, or both combined. An ordinary 50-gallon barrel has a buoyancy of about 400 pounds when completely submerged; those of other sizes in proportion to their capacity. The supporting power of any barrel or keg can be determined with sufficient accuracy by weighing it when full of water and again when empty; the difference will be the supporting power.

The number of barrels required for a pier is obtained by dividing the total load to be borne by the supporting power of one barrel. A margin of 20 or 25 per cent should be allowed, as the barrels of a pier must not be completely submerged.

In forming the piers the barrels are laid out in line with the bungs uppermost. The gunwale timbers are placed over and the rope slings under the ends, the slings secured to the gunwales at each end of the line. Between each pair of barrels on each side a brace is secured to the sling and then led around the gunwale on its own side, round the opposite brace rope and back again to its own gunwale, where it is made fast (figs. 171, 172, and 173). Care must be taken in launching to avoid injuring the ropes by chafing on the ground.

The rafts so formed may be united into larger ones as indicated in gure 174.

Where timber is available the best method of forming a barrel pier make an inverted box crib of lumber or timbers nailed, bolted, or d together. If the crib is as strong as it should be, it may be d over the barrels, which will require no other fastenings. 75 shows this method.

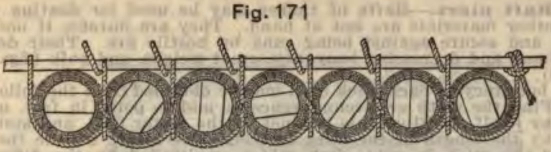


Fig. 171

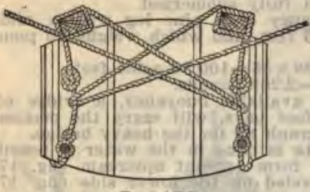


Fig. 172

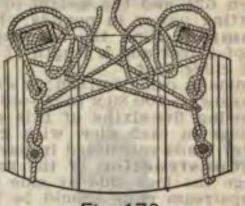


Fig. 173

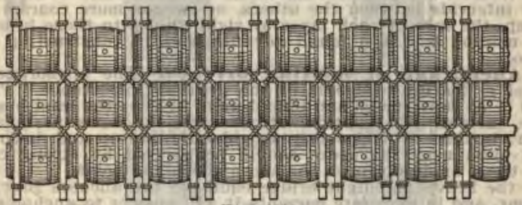


Fig. 174

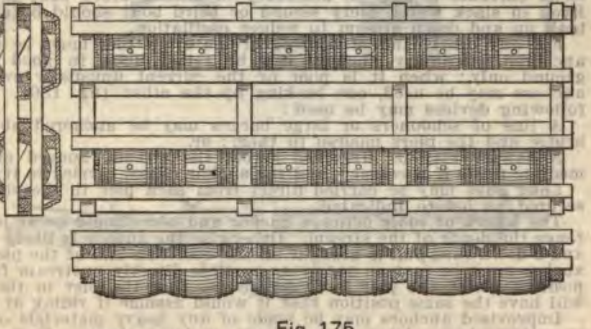


Fig. 175

93. **Raft piers.**—Rafts of timber may be used for floating piers when other materials are not at hand. They are durable if not disturbed and secure against being sunk by hostile fire. Their defects are: Small and decreasing buoyancy, great weight, and bulk (figs. 176 to 179).

The buoyancy of each stick used may be obtained from the following rule: Find the girth or circumference at middle point in feet, multiply it by itself, multiply this product by the factor 0.08, and multiply again by the length of the stick in feet. The result will be the volume of the stick in cubic feet, which, multiplied by the difference between $62\frac{1}{2}$ and the weight of a cubic foot of the timber, gives the supporting power in pounds when fully submerged.

Example: Find the net buoyancy of a pine log with a middle girth of 6 feet and a length of 35 feet, and which weighs 40 pounds to the cubic foot.

Volume in cubic feet $= 6 \times 6 \times 0.08 \times 35 = 100.80$ cubic feet.

Buoyancy $= 100.80 \times (62\frac{1}{2} - 40) = 2{,}268$ pounds.

Allowing five-sixths of this as available buoyancy, a bridge of 7 such logs in each pier, with 20-foot bays, will carry the maximum infantry loads calculated in paragraph 85 for the heavy bridge.

94. **Construction** of the **rafts** is done in the water if possible. Arrange the logs side by side to form a point upstream (fig. 177). The upstream ends should be beveled on the lower side (fig. 176). The logs are held together by cross timbers pinned or spiked over the tops. Where the logs are of small size additional sticks may be placed in the intervals between the others, or two or more courses may be built up, the logs of each layer at right angles to those below. The latter method has been found advantageous in constructing rafts of bamboo.

95. **Anchorage of floating bridges.**—The anchorage of the piers of a floating bridge is of the greatest importance. The piers should be so constructed and placed as to present the least obstruction to the current. In nontidal streams all the bows are placed upstream; in tidal estuaries they should alternate up and down stream.

The piers near the shore should be secured by strong cables to rocks, trees, or deadmen on the shore above and below.

For the heavy and light bridge equipage the anchors provided are sufficient, and in moderate currents it will answer to anchor alternate boats upstream and every fourth one downstream; the downstream anchors always on boats which have upstream anchors also. In swift currents it may be necessary to anchor every boat upstream. Even in slack water every second or third boat should be anchored both up and down stream to reduce oscillation.

For any other kind of floating bridge every pier must be securely anchored. Ordinary anchors can be relied upon in good holding ground only; when it is poor or the current unusually swift two anchors may be used, one backing up the other (fig. 180). Or the following devices may be used:

A line of schooners or large barges may be anchored above the bridge and the piers moored to them; or,

A hawser may be stretched across the stream, buoyed on intermediate floats if necessary, and the anchor cables carried to it; or,

Long guys may be carried direct from each pier to the shore and secured as before indicated.

The *length of cable between anchor* and *pier* should be at least *ten times* the *depth* of the stream. Otherwise the anchor is likely to drag and a downward pull is brought on the upstream end of the pier. The anchor must be cast as nearly as possible directly upstream from the position which the pier is to occupy, so that the pier in the bridge will have the same position that it would assume if riding at anchor.

Improvised anchors may be made of any heavy materials on hand, ailway iron, pieces of machinery, or large stones. Such anchors be of considerable weight, as dependence is placed on their ather than their attachments to the bottom.

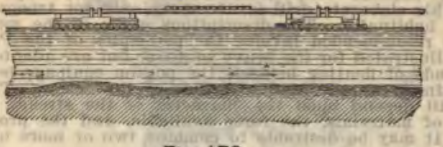


Fig. 179

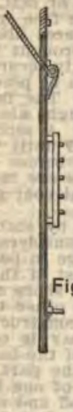


Fig 178

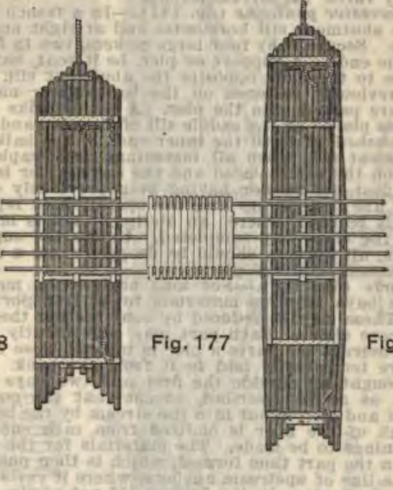


Fig. 177

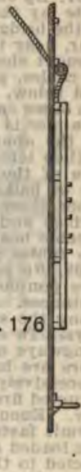


Fig. 176

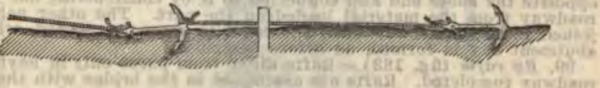


Fig. 180

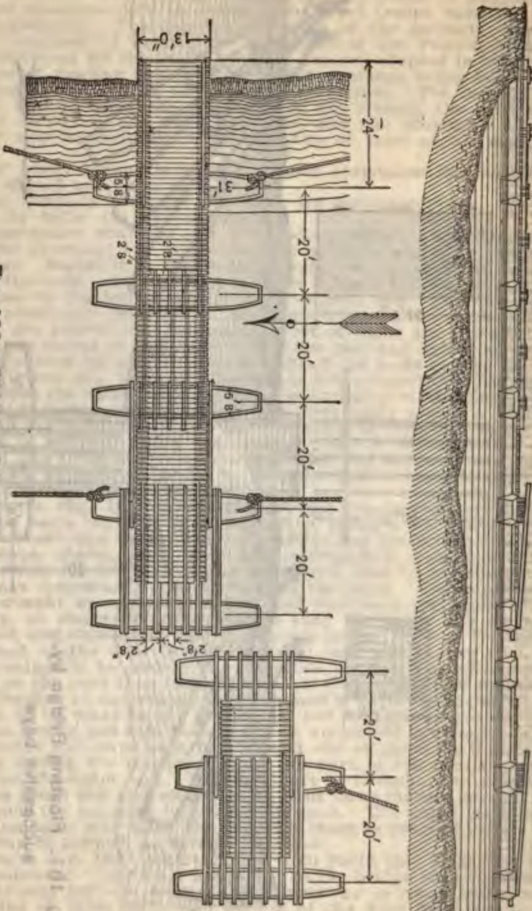


Fig. 182. Floating Bridge by parts.

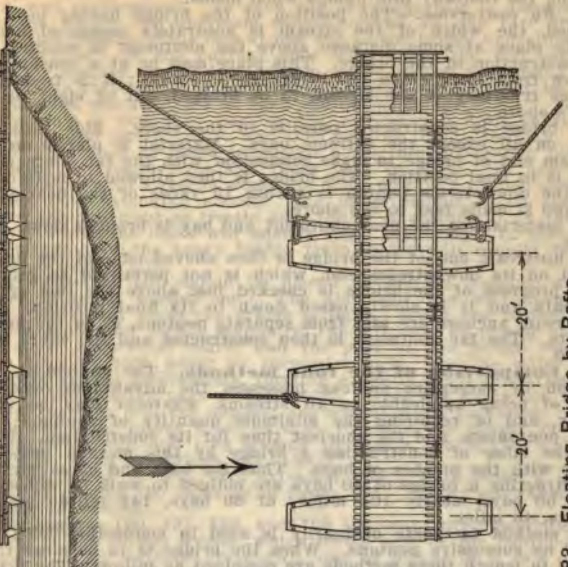
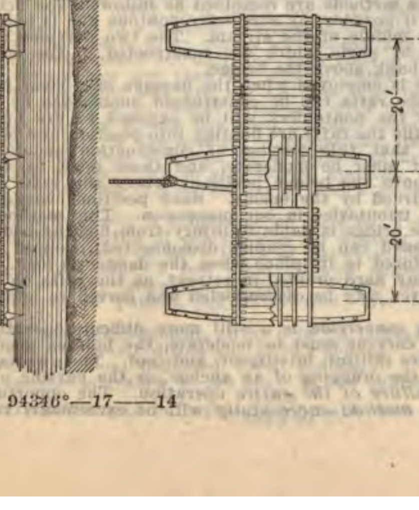



Fig. 183. Floating Bridge by Rafts.

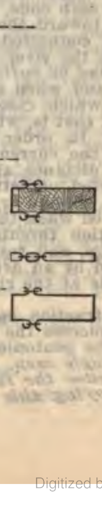


Fig. 184.

This method is not often employed, as it requires more piers for the same length of bridge and distributes the support unequally, throwing the roadway into humps when loaded.

100. *By conversion.*—The position of the bridge having been determined, the width of the stream is accurately measured and a suitable place at some distance above the abutment is selected for the construction of the bridge. This place may be at a considerable distance from that which the bridge is to occupy; it is frequently on some tributary of the stream to be bridged, out of sight of the enemy's shore.

The bridge is constructed parallel to the shore. Side rails are lashed on all except the extreme bays. Material is placed on the upstream end of bridge to make connection with the far shore when bridge is in final position. The bridge is then allowed to float down until the downstream ponton is within 15 yards of the near abutment and is made fast to the shore.

The material for the near abutment and bay is brought down in a ponton.

The upstream end of the bridge is then shoved off and the bridge pivoted on its downstream end, which is not permitted to ground.

The progress of the bridge is checked just above the line of the abutments and it is slowly eased down to its final position. The downstream anchors are cast from separate pontons, as in the bridge by parts. The far abutment is then constructed and the shore bays are laid.

101. **Comparison of the four methods.**—The method of construction by *successive pontons* possesses the advantages over the others of being applicable to all streams, whatever may be their velocity, and of requiring the minimum quantity of equipage, the fewest pontoniers, and the shortest time for its construction. However, the labor of constructing a bridge by this method increases rapidly with the number of bays. Thus the balk and chess carriers in constructing a bridge of 40 bays are obliged to walk 6¾ miles; in one of 50 bays, nearly 10½ miles; of 60 bays, 14¾ miles; and of 100 bays, 40 miles.

The *method by parts* ordinarily is used in connection with the method by successive pontons. When the bridge is to be more than 40 bays in length these methods are combined as follows: The bridge is begun at both ends, if possible, by successive pontons and is pushed on rapidly toward the middle of the stream. The two portions thus formed are connected by parts which are constructed in the meanwhile along the river bank above the bridge.

The *method by rafts* is employed when the passage of a river is to be forced, and when the rafts can be constructed unobserved by the enemy, in which case the pontoniers will be exposed to fire but a short time; that is, while the rafts are floating into position and being connected. In order that this method of construction should be successful, the current must be moderate, and there must be at a reasonable distance above the bridge positions where the rafts can be constructed undisturbed by the enemy. Such positions would be afforded by islands or tributaries in our possession. This method is also employed when the bridge is liable to injury from floating bodies, as the portion threatened can be readily disconnected, dropped out of the bridge, and restored to its place when the danger is past. It may be used by an army hard pressed in retreat, as the rafts on the enemy's side of the river may be disconnected and moved to a place of safety.

The *construction by conversion* is a still more difficult operation. To insure success the current must be moderate, the holding ground good, and the pontoniers skillful, intelligent, and cool. The awkwardness of a single man, the dragging of an anchor, or the parting of a cable may cause the failure of the entire operation. The opportunities for employing this method successfully will be exceedingly rare.

102. *Draw spans in floating bridges* (fig. 185).—To form a draw a raft is introduced into the bridge over the channel of navigation. The attachments of the false balks are adapted to convenient removal and replacement. To open the draw the raft is disconnected from the bridge, the upstream cables slacked off, the raft dropped out of the opening, made fast at one end to the bridge and allowed to swing around. If the current does not suffice, the raft must be moved by hauling on the down-stream cables and on a swinging cable laid for the purpose. A wide draw in a strong current may be made of two rafts, one swinging on each end of the bridge.

The draw is closed by hauling the raft around until parallel to the bridge and just below it, and then hauling it into the gap.

103. *Care must be taken* to provide a free hinging motion between abutment or trestle bays and those next to them. In case of a staunch boat with straight sides, the balks may join on one gunwale, one set only extending across. The hinge should be on the side toward the abutment or trestle (fig. 186). A saddle sill on the first pier to receive the balks will answer (figs. 187, 189). In fact, with the exception of the heavy bridge train, balks will usually be supported on saddle sills.

The *abutment sill* should be placed as low as possible without danger of being washed out. The abutment bay will usually be nearly horizontal when the bridge is light. When the bottom is of mud or sand, and shoals gradually, the sill may be placed about 2 feet above high-water mark, and the part of the bridge near the shore built at high water by successive bays. As the water falls, the piers ground successively, forming a gentle ramp from the abutment to the floating part of the bridge. Ordinary boats can not be so used, as they will not support the weight when grounded. If the banks are high, ramps must be dug, reaching the proper level for the abutment sill, and long enough to give a practicable slope for the traffic using the bridge (fig. 189).

A bridge may be laid with extended intervals to cover a greater length by placing the balks as in figure 188. Proper allowance must be made in loading.

104. Figures 190, 191, 192, and 193 illustrate the assembling and placing of the *Birago trestle,* which forms part of the ponton-bridge equipage. Two methods are shown, one by means of a raft of two boats, and the other by a single boat. In either method the trestle assembled and in a vertical position is brought up to the end of the bridge, the trestle balks placed on the cap and lashed, and the boat or raft then pushed out until the inner ends of the balks fall in place. The trestle legs are then let go, and when the shoes are on the bottom the false legs are set and the boat or raft removed. The Birago trestle is no longer furnished with modern ponton equipage. A new type of trestle has been adopted differing from the Birago trestle mainly in the manner of supporting the cap. It consists of a cap with pins, two legs with shoes and keys, and two wedges. The legs are inclined, to give lateral stability. The cap is adjusted by means of two cap levers, one of which is carried on each trestle wagon.

The new trestle is illustrated on page 62, Ponton Manual, 1915.

105. **Examples** of calculations for floating bridges:

To find length of bay: Piers of flat-bottomed boats with vertical sides, 5 feet wide, 3 feet deep, allowed immersion 2½ feet. Mean length of part immersed, 16 feet. Weight of boat=1,000 pounds. Dead load, 80 pounds per linear foot; live load, 560 pounds per linear foot.

Maximum displacement, 16 by 5 by 2½ feet=200 cubic feet.
Weight of water displaced, 12,500 pounds.
Weight of boat deducted, 1,000 pounds.
Available buoyancy of one boat, 11,500 pounds.

Maximum length of bay$=\frac{11500}{560+80}=$18 feet nearly.

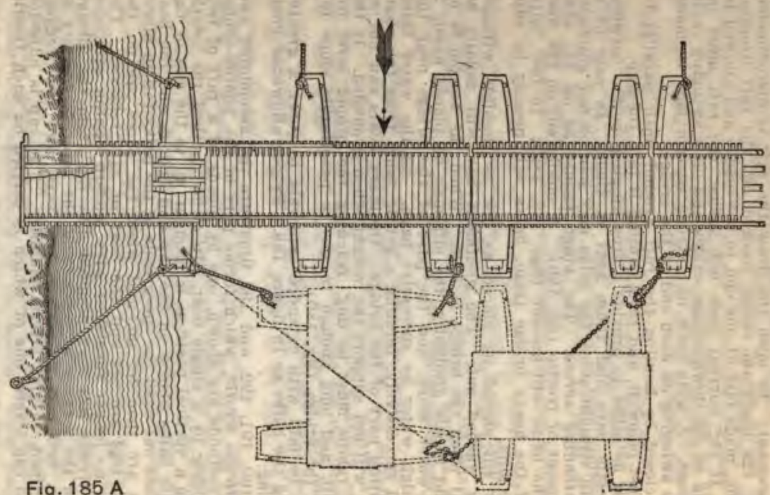


Fig. 185

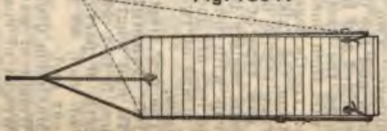


Fig. 185 A

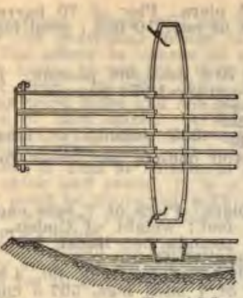


Fig. 186.

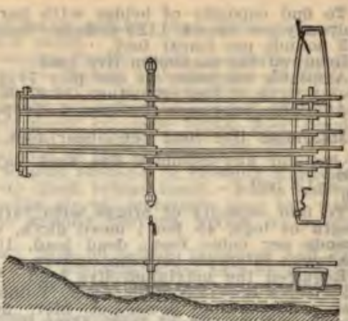


Fig. 187.

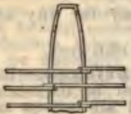


Fig. 188.

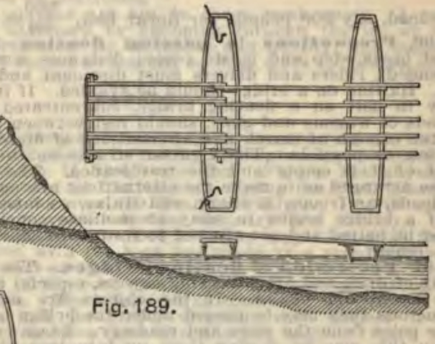


Fig. 189.

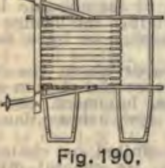


Fig. 190.

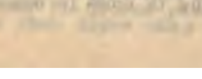


Fig. 193.

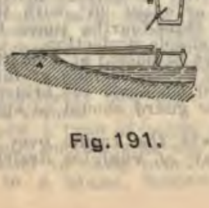


Fig. 191.

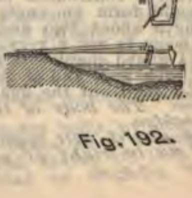


Fig. 192.

To find capacity of bridge with barrel piers: Pier of 70 barrels, buoyancy per barrel, 112½ pounds; length of bay, 10 feet; dead load, 105 pounds per linear foot.

Required the maximum live load:

Available buoyancy of one pier 112½×70×.8=6,300 pounds. Deduct weight of superstructure, 10×105 pounds=1,050 pounds.

Available buoyancy per bay, 5,250 pounds.

Maximum live load per linear foot, $\frac{5250}{10}=525$ pounds, or length of bay for any assumed live load, say 400 pounds per linear foot, $\frac{5250}{400}=13$ feet+.

To find capacity of bridge with raft piers: Piers of 7 logs each; length of logs, 45 feet; mean girth, 4½ feet; weight of timber, 35 pounds per cubic foot; dead load, 150 pounds per linear foot of roadway; intervals between centers of piers, 19 feet.

Required the maximum live load: Volume of log, par. 90, 4.5×4.5×0.08×45=72.5 cubic feet. Volume of 7 such logs, 507.5 cubic feet. Supporting power of pier, 507.5×(62.5−35)×0.8=11,160 pounds. Deduct dead load, 150×19=2,850 pounds. Net buoyancy per bay, 8,310 pounds. Maximum live load for 19-foot span, $\frac{8310}{19}=437$ pounds per linear foot, or length of bay for any assumed live load, say 500 pounds per linear foot, $\frac{8310}{500}=16.6$ feet.

106. **Precautions in passing floating bridges.**—Infantry must break step and music cease; distances must be maintained or extended; riders and drivers must dismount and all horses must be led. Halting on a bridge should be avoided. If it is absolutely necessary to halt on a floating bridge, concentrated loads, such as the wheels of wagons and guns, should rest between piers. Interruptions of the column of march and alternations of direction should be made as few as possible. The greatest strains on the bridge occur when part of it is empty and the rest loaded. The column should also be so arranged as to make the alternations among the different classes of loads, as troops, artillery, and trains, as infrequent as possible.

If a bridge begins to sway or oscillate considerably, the column must be halted and not allowed to resume its march until the swaying has ceased.

107. **Protection of floating bridges.**—The bridge must be kept clear of drift and other floating objects, especial attention being given to the anchor cables. If the objects are not too large or too numerous they may be passed under the bridge by men working with pike poles from the piers and roadway. Large trees may be disposed of in this way by sawing them up into logs of manageable length. Floating objects may be prevented from striking the bridge by a guard upstream or by a draw span in the bridge or by a floating boom crossing the stream obliquely.

A guard, if used, is placed about 1,000 yards above the bridge. It is stationed in boats at different points across the stream and is provided with cables, grapnels, anchors, dogs, hammers, saws, etc. The business of this guard is to anchor or tow ashore dangerous drifting bodies.

The floating boom is constructed of trees united by chains and forms a continuous barrier to surface drift. Its general direction should form an angle of about 20° with the current, giving it a length about two and three-fourths times the width of the river. A boom is not a very reliable protection.

A guard should always be posted at a floating bridge with a sentry [illegible]nd, and if the bridge is long at intermediate points. Sen-[illegible] out the guard whenever the bridge is in danger from any [illegible]e body of the guard should be stationed near one end of [illegible]

[illegible]rd will regulate the traffic over the bridge and enforce [illegible]to right of way of vehicles desiring to cross in opposite directions. They will see that loads greater than those prescribed for the particular bridge do not enter.

The officer in charge of a floating bridge must frequently inspect the cables to see that they are not chafing and that the anchors do not drag. He will cause rack lashings to be tightened up when they work loose and see that boats are bailed or pumped when they leak or ship water. A suitable depot of spare balks, floor planks, cordage, etc., should be established on shore near one end of the bridge. The guard will be stationed at the same end.

Ice, if thin or rotten, is a serious obstacle to crossing a stream; if thick and sound, it is a very good bridge itself. Boats used in ice must be protected with chafing pieces, especially near the water line at the bows. Heavy ice, rapidly moving, makes a crossing impracticable.

With sound ice, infantry may pass on 3-inch thickness and cavalry on 4, but with large intervals. Fieldpieces are safe on 6 inches, and ice 10 inches thick will carry any load that an army is likely to have.

Loads may be carried on lesser thicknesses or on unsound ice by distributing the weights. Infantry may cross on lines of planks. The wheels of wagons may be skidded on planks. Wagon boxes may be placed on boards and used as sleds to cross supplies. Animals may be hauled across on platforms.

In shallow lakes, springs are apt to cause weak spots. A path should be carefully examined by chopping through the ice at frequent intervals to determine its thickness and quality, and when a safe track is found it should be marked on both sides by bushes stuck in holes in the ice.

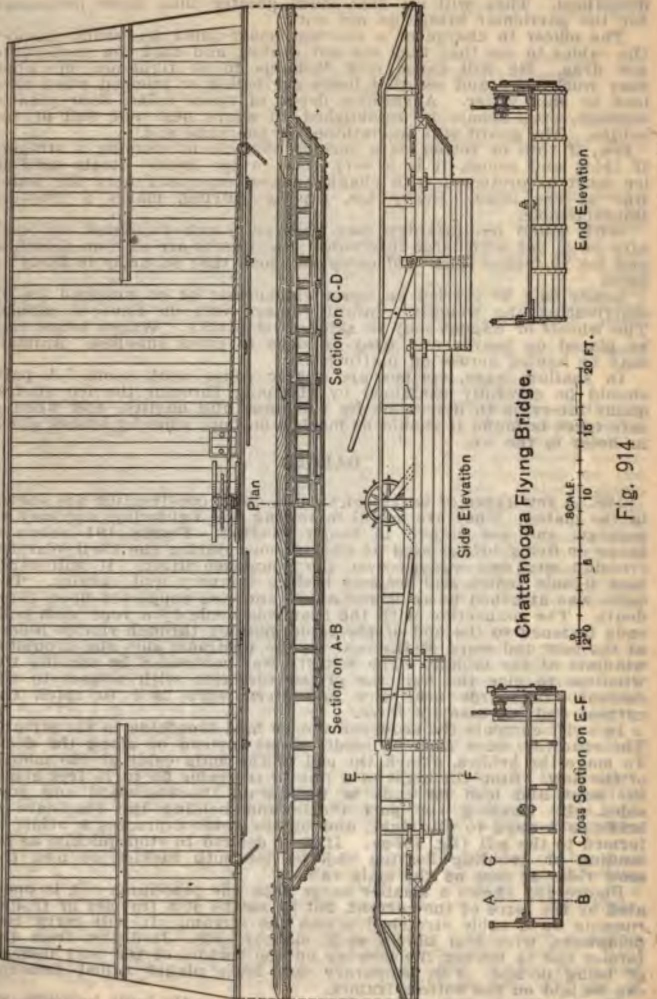
BARGES.

108. A few types of barges of simple, quick construction are shown in the plates. They are useful in towing and lightering, are easy to manage, and are stanch in rough weather. Figure 194 shows a barge or flying bridge used at Chattanooga during the Civil War for crossing men and wagons over the Tennessee River. It will carry four 6-mule teams and wagons besides infantry and cavalry. The cable was attached to an island above and was supported upon three floats. The connection with the boat was made by a rope with both ends fastened to the end of the cable, passing through snatch blocks at the bow and stern of the boat on the upstream side and around a windlass at the middle. The velocity was controlled by turning the windlass to give the hull the proper direction with respect to the current. Leeboards near bow and stern were used to catch the current and increase its force.

In swift currents the scow can not be held broadside to the stream. The roadway must then be made across instead of along the deck. To make the bridles, attach the end of the main cable at the middle of the bow. Stop the bight of a line to the cable 50 to 75 feet above the scow and lead its ends to tackles on the starboard and port sides. By slacking the port tackle and holding the starboard a bridle is formed to the right, and by the reverse process a bridle is formed to the left (fig. 185*a*). If it be desired to stop quickly, as on landing or avoiding floating objects, let both tackles go and the scow rides at ease on the main cable.

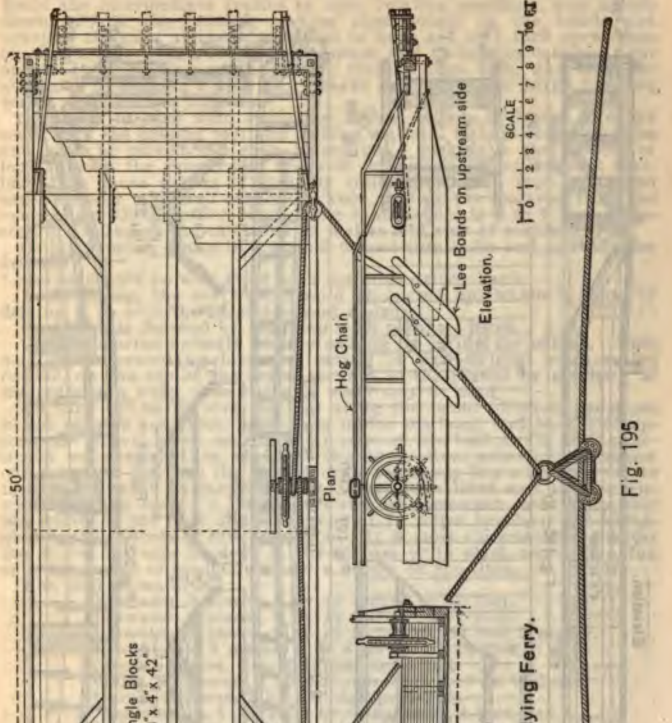
Figure 195 shows a smaller barge than the preceding. It is operated by the force of the current, but by means of a traveler or trolley running on a cable stretched across the stream. It will carry two fieldpieces, with four horses each, side by side. It differs from the former one in having the flooring on the bottom of the boat instead of being decked. For temporary use, loose planks called *dunnage* can be laid on the bottom frames.

Figures 196 to 199 show a type of barge easily built by ordinary carpenters. It is best built bottom side up. Place skids or ways on or near the ground parallel to each other and about 10 feet apart with their *upper sides* in a plane, horizontal or slightly inclin



Chattanooga Flying Bridge.

Fig. 914



Scow for Flying Ferry.

Fig. 195

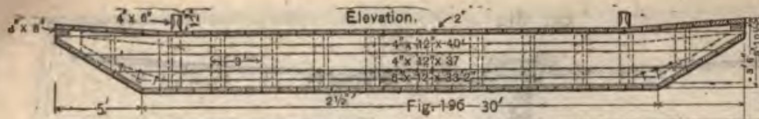
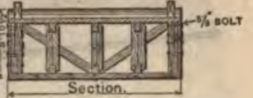


Fig. 196



Section.
Fig. 198

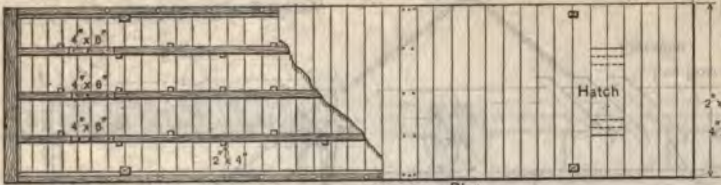


Fig. 197 Plan

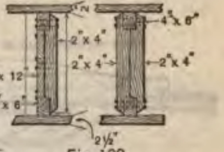


Fig. 199

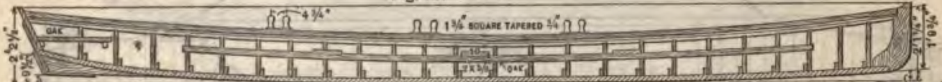


Fig. 200

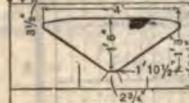


Fig. 201

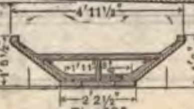


Fig. 202

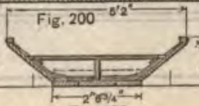


Fig. 203

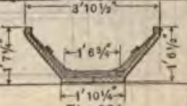


Fig. 204

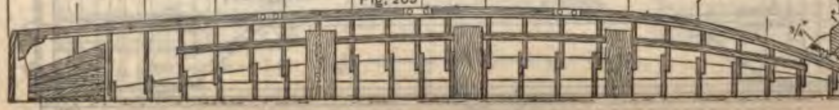


Fig. 205

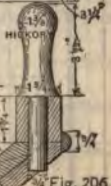


Fig. 206

Get out the gunwales complete, with timberheads attached, and place them on the ways in their relative positions, but upside down. Build the intermediate frames in their relative positions, also upside down. Plank the bottom, making close joints on the inside and beveling the plan at the edges so as to have a ⅛ to ¼ inch open seam on the outside. This is called *outgauge* and facilitates calking. Put on the head blocks and the corner irons. Then calk, and stay the gunwales by spiking a few deck planks on. Slide the barge into the water, still bottom side up.

Calking is done with oakum or cotton, which is driven into the seam with the calking tool and calking mallet. Oakum comes in bales and must be picked and spun before use. Picking is the process of loosening up the compressed fibers of the oakum by pulling and beating. The loose oakum is spun by rolling it into a rope or strand usually under one hand across the knee, feeding the material from the loose pile with the other hand. The spun oakum is ½ to 1 inch diameter, according to the thickness of planks and size of seams.

Calking cotton comes in a strand wound into balls and is ready for driving.

Seams should be well filled with material driven hard.

In recalking, the old work should be *horsed up,* which is done by driving it in with the large tool and a sledge.

The seam is finished by a *paying* with paint or pitch.

Certain marine animals destroy calking by eating the oakum. This may be prevented by laying a strand of hard-twisted rope, called *ratline,* on the top of the seam, secured to the planks by staples. If the seams are wide, wide strips of wood may be used.

To turn the barge over, lay her along the bank. Fasten two lines to the outside gunwales, pass them under the boat, and lead well upstream. Shovel earth on the outer edge of the bottom till it is practically submerged, then slack off the upper line, allowing the upper end to swing out into the stream until the barge lies with one end to the bank instead of the side. Hold fast both lines and the current will right the boat. A depth of water of somewhat more than half the width of the boat and a current of 1½ miles per hour are necessary to the success of this operation. It is most conveniently done at the shore, but may be done in the stream or in slack water if a tug or other means is available to set a strain on the lines.

109. Bill of materials:

Gunwales, 2 pieces, 4 by 12 inches by 40 feet.
Gunwales, 2 pieces, 4 by 12 inches by 37 feet.
Gunwales, 2 pieces, 6 by 12 inches by 33 feet 2 inches.
Head blocks, 2 pieces, 8 by 8 inches by 10 feet.
Knees, 6 pieces, 4 by 6 inches by 3 feet.
Struts, 42 pieces, 2 by 4 inches by 2 feet 10 inches.
Braces, 4 pieces, 2 by 4 inches by 7 feet.
Timberheads, 4 pieces, 4 by 6 inches by 4 feet, oak.
Deck stringers, 3 pieces, 4 by 6 inches by 40 feet.
Floor stringers, 3 pieces, 4 by 6 inches by 33 feet.
Bake stringers, 6 pieces, 4 by 6 inches by 6 feet.
Bottom planks, 45 pieces, 2½ by 12 inches by 10 feet.
Deck planks, 43 pieces, 2 by 12 inches by 10 feet.
Driftbolts, 20, ⅝-inch by 3 feet 10 inches.
Driftbolts, 4, ⅝-inch by 2 feet 6 inches.
Driftbolts, 4⅝ by 12 inches.
Driftbolts, 4, ⅝ by 8 inches.
Carriage bolts, 20, ⅝ by 9 inches.
Carriage bolts, 12, ⅝ by 12 inches.
Spikes, 6-inch, 150 pounds.
Spikes, 5-inch, 250 pounds.
Corner bands, 4, $\frac{3}{16}$ by 4 inches by 4 feet.
Countersunk-head spikes, 40, ½ by 4 inches.
Oakum, 30 pounds.
Pitch or seam paint, 5 gallons.

Figures 200 to 206 show a skiff easily constructed and valuable for a number of purposes. It may be 18 to 26 feet long, with parts proportioned as in the drawings.

Figures 207 and 208 show a design for a 100-foot barge. This barge is of greater dimensions than any of the preceding and somewhat more elaborate in construction. It was designed specially for carrying stone and would be useful in heavy water transportation generally. The construction is shown in detail and to scale and is within the limits of ordinary rough carpentry. It should be built on ways, top side up, and planked from below.

CANTILEVERS.

110. A **cantilever** is a projecting or overhanging support, transmitting all of its load to one of its ends.

The cantilever principle may be utilized in military field bridges for short spans and moderate loads. Some typical forms are shown in figures 209 to 212. The main points to be observed are that the maximum pressure on the abutment is greater than the heaviest load, live and dead, on the projecting part of the cantilever; that any settlement of the abutment causes a greater disturbance of the bridge; and that the weight or resistance of the anchor multiplied by its distance from the abutment must be greater than the greatest concentrated load multiplied by the length of the projecting part, or the greatest uniform load multiplied by half that length.

If the anchorage is beneath the beams as in figures 209 and 210, the roadway may be laid directly upon them. If the anchorage is above the beams, separate road bearers must be provided resting on transoms carried by the cantilevers, and high enough at the inner end to pass over the anchorage; or the cantilevers may be at the sides only, as in figures 211 and 212.

Bear in mind that the *safe load* of a cantilever, concentrated or uniform, is one-fourth of the corresponding safe load of the same beam supported at both ends with the same span, and that the *deflection* of the cantilever under any load less than the safe load will be ten to sixteen times greater than the deflection of the same beam under the same load when supported at both ends. Much greater vibrations must be expected than in girder or truss bridges.

If the two cantilevers meet at the middle of the bridge they must be fastened together. This doubles the safe concentrated load for the bridge, making it equal to one-half the safe uniform load of both cantilevers instead of one, or one-half the safe concentrated load on a beam of the size and length of one cantilever supported at both ends.

When separate road bearers are used, the transoms are better arranged so that there will be a middle bay resting one end on each cantilever (figs. 211 and 212).

If the cantilevers do not meet, the gap is filled by a girder or truss supported by the ends of the cantilevers. This arrangement may be useful in case timbers too short to span the gap have to be used. To get the maximum strength for timbers of a given size, the cantilevers should be one-seventh and the girder five-sevenths of the span.

111. When objects of sufficient mass and stability are available, the counterbalance is not necessary and the cantilevers take the form of brackets (fig. 213). If the opposite brackets meet and are well connected the structure becomes of the spar-bridge type, and there is no overturning moment on the abutments. Abutments which will sustain the weight of the cantilevers themselves and the working parties before they are connected will permit the construction of such a bridge. The two brackets on the same side should be connected by diagonals.

112. The horizontal and inclined members of a bracket are single sticks, or built up as may be most convenient. They are connected

Design for a large Barge.

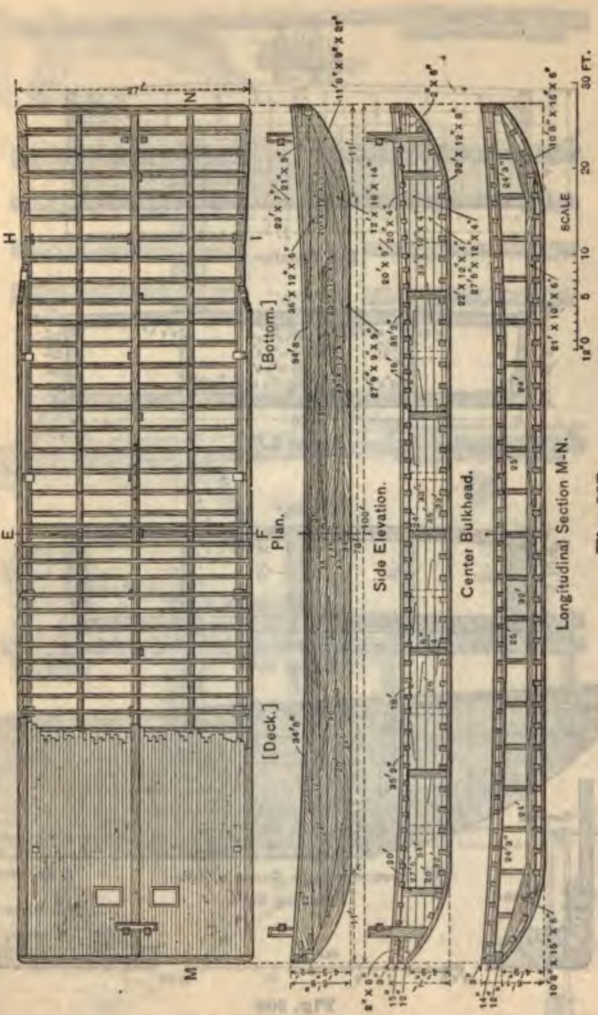
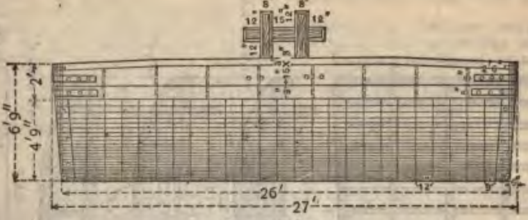
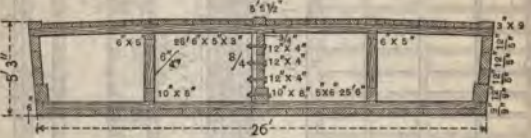


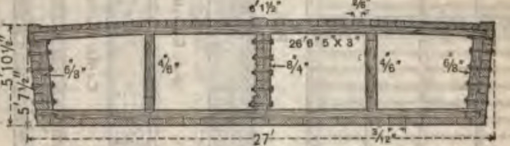
Fig. 207



End Elevation.



Section E-F.



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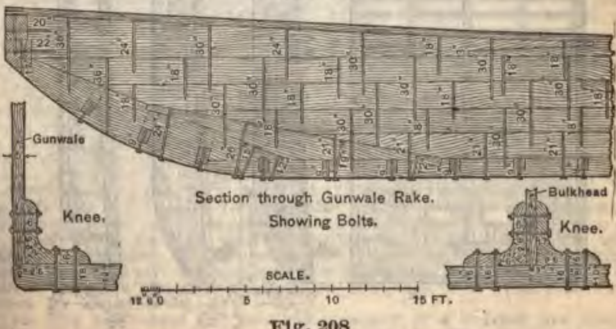


Section through Gunwale Rake.
Showing Bolts.

Knee.

Knee.

Fig. 208

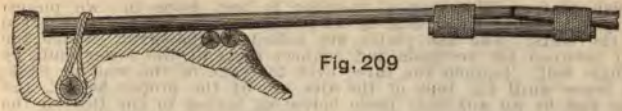


Fig. 209

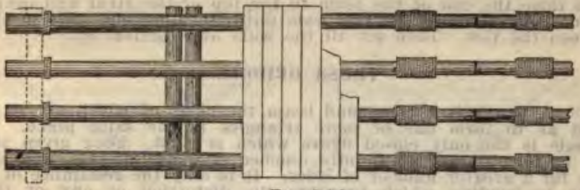


Fig. 210

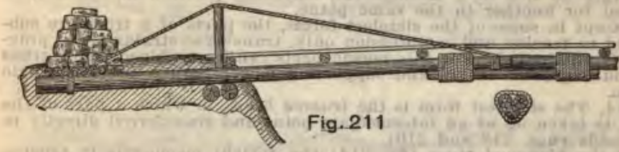


Fig. 211

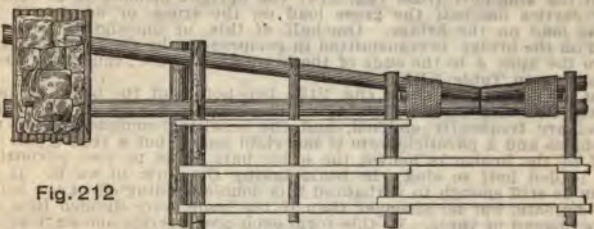


Fig. 212

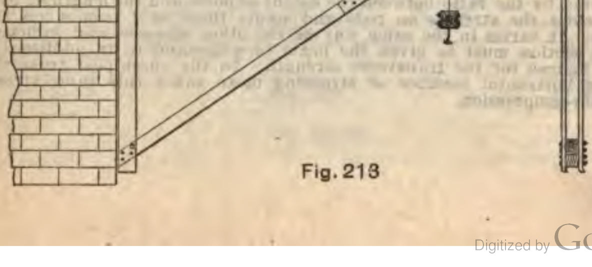


Fig. 213

by fish plates. The vertical member is best made in two pieces. The parts should be accurately assembled on the ground and bored for the bolts. The fish plates are bolted to the strut. Place the strut between the verticals and connect them at the lower ends by a single bolt. Launch the three over the edge of the wall or bank, and lower until the tops of the ties are at the proper height, and make fast by an auxiliary piece bolted or lashed to the ties on the outside, leaving the strut free to rotate about the bolt at its foot. Then raise the end of the beam to the top of the strut and connect by one bolt. Launch out the beam until its inner end falls in place between the ties. Then set all the bolts and tighten up.

TRUSS BRIDGES.

113. A **truss** is a compound beam the parts of which are so disposed as to form one or more triangles in the same plane. The triangle is the only closed figure which is rigid. Four given sides may be formed into an infinite number of quadrilaterals, and similarly for a greater number of sides. It is only the resistance of the joints to bending which prevents the distortion of any of these figures, or its complete collapse. But a given three sides can be formed into one triangle and only one; hence, if the joints do not separate no side of a triangle can leave the position in which it is placed for another in the same plane.

Except in some of the simplest forms, the parts of a truss are subjected to tension and compression only, transverse strains being practically eliminated. For this reason parts can be combined into a truss of much greater length and supporting power than a possible single beam.

114. The simplest form is the *trussed beam*, in which a part of the load is taken up at an intermediate point and transferred directly to the ends (figs. 218 and 219).

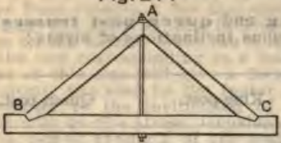
In the *king-post* truss (fig. 214) the upright member is in tension and carries one-half the gross load on the truss, or one-fourth the gross load on the bridge. One-half of this, or one-eighth the gross load on the bridge, is transmitted in compression by the inclined struts from the apex *A* to the ends of the beam at *B* and *C*, causing stresses, as shown in Table XXX.

In the *queen-post* truss (fig. 215) two points of the beam are supported, forming three equal bays. The counter braces in the middle panel are frequently omitted, and the resulting combination of two triangles and a parallelogram is not rigid and is not a true truss. As half of the bridge is loaded the other half tends to rise, permitting the loaded half to sink, the beam taking the form of an S. If the beam be stiff enough to withstand this double bending effect the bridge will be safe, but no stronger than if the beam were divided into two bays instead of three. In this form each post carries one-sixth of the total load, dead and live, on the bridge, all of which is transmitted down the corresponding strut.

115. The *stresses* in king and queen post trusses depend upon the *load* and the *inclination* of the struts. The load may be stated in tons or pounds for the entire bridge. The inclination of the struts is represented by the ratio between the height of posts and the length of bay.

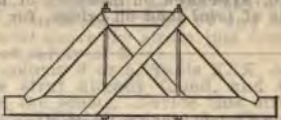
Besides the stresses on rods and struts there is a *tension* on the *beam*. It varies in the same way as the other stresses, and sufficient cross section must be given the beam to withstand it, in addition to that figured for the transverse strength. In the queen-post truss the upper horizontal member or straining mean takes this same stress, but in compression.

Fig. 214



King Post Truss

Fig. 215



Queen Post Truss

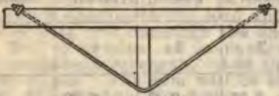


Fig. 216

Inverted King Post Truss

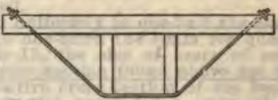


Fig. 217

Inverted Queen Post Truss

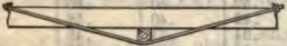


Fig. 218

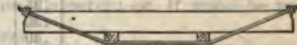


Fig. 219

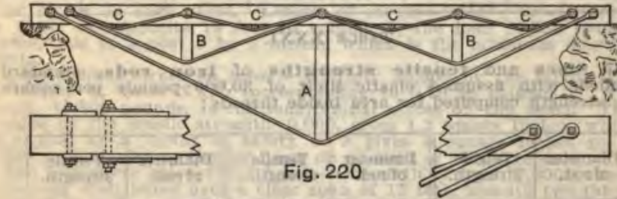


Fig. 220

Fink Truss

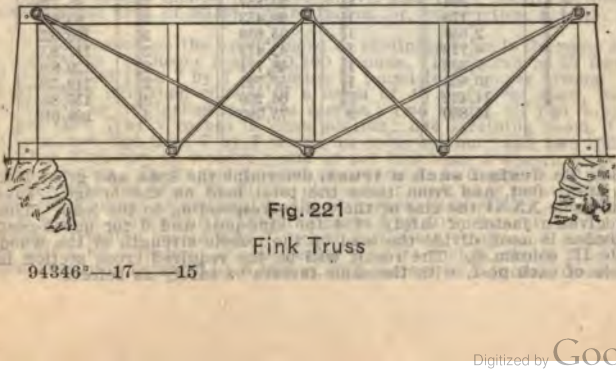


Fig. 221

Fink Truss

TABLE XXX.

116. **Stresses** on members of **king** and **queen post trusses** in terms of *total load* on bridge, for various inclinations of struts:

Ratio of height of post to length of bay.		King-post.		Queen-post.	
		Stress on each strut.	Stress on each beam.	Stress on each strut.	Stress on each beam.
1		2	3	4	5
Customary range for inverted truss	0.05	2.50	2.49	3.33	3.33
	.10	1.25	1.24	1.66	1.66
	.15	.84	.83	1.12	1.11
	.20	.64	.62	.85	.83
	.25	.52	.50	.69	.66
	.30	.42	.40	.58	.55
	.40	.34	.31	.45	.42
Customary range for erect truss...	.50	.28	.25	.37	.33
	.60	.25	.21	.32	.28
	.70	.22	.18	.29	.24
	.80	.20	.16	.27	.21
	.90	.19	.14	.25	.18
	1.00	.18	.12	.23	.17

TABLE XXXI.

117. **Sizes and tensile strengths of iron rods,** standard threaded, with assumed elastic limit of 30,000 pounds per square inch, strength computed for area inside threads:

Diameter of rod.	Tensile strength.	Diameter of rod.	Tensile strength.	Diameter of rod.	Tensile strength.
Inches.	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*
$\frac{1}{8}$	294	$1\frac{1}{8}$	23,857	$2\frac{1}{8}$	85,119
$\frac{1}{4}$	1,178	$1\frac{1}{4}$	29,453	$2\frac{1}{4}$	95,426
$\frac{3}{8}$	2,650	$1\frac{3}{8}$	35,638	$2\frac{3}{8}$	106,322
$\frac{1}{2}$	4,712	$1\frac{1}{2}$	42,412	$2\frac{1}{2}$	117,809
$\frac{5}{8}$	7,363	$1\frac{5}{8}$	48,774	$2\frac{5}{8}$	129,886
$\frac{3}{4}$	10,603	$1\frac{3}{4}$	57,727	$2\frac{3}{4}$	142,552
$\frac{7}{8}$	14,432	$1\frac{7}{8}$	66,269	$2\frac{7}{8}$	155,803
1	18,850	2	75,399	3	169,646

118. **To design such a truss,** determine the span and gross load
ear feet, and from them the total load on the bridge. Take
able XXXI the size of the rod corresponding to the load. This
ves a factor of safety of 4 for king-post and 6 for queen-post.
er is used, divide the load by the tensile strength of the wood,
I, column 3. The result will be the required cross section in
each post, with the same factors of safety as before.

To determine the size of struts, divide the length of post by length of bay, and with the quotient enter Table XXX and take out the factor from column 2 for king-post or column 4 for queen-post truss. Multiply the load by the factor. The result will be the maximum stress on the strut. With the length of strut enter Table IV and take out the size corresponding to a load next above the strain just found. Sticks of this size will give a factor of safety of 5.

Multiply the load by the factor in column 3 or 5, Table XXX, corresponding to the inclination of the strut already found, and the result will be the stress (tension) *on the beams.* Divide this stress by the tensile strength of the material, Table II, column 3. The result, multiplied by 5, will be the square inches of cross section to be allowed for this stress, with a factor of safety of 5. Unless the posts are short, this strain may be neglected.

Consider one-fourth the load applied uniformly to one-half the beam for king-post and one-sixth the load to one-third the beam for queen-post, and determine, as in paragraph 13, the size of beam of sufficient transverse strength. Add the cross section found above for the tensile strain. The sum will be the entire cross section of the beam.

119. **Example.**—To design a queen-post truss for a span of 45 feet, a dead load of 150 pounds, and a live load of 850 pounds per linear foot, or 1,000 pounds gross. Total load, 45,000 pounds. Assume height of posts at 10 feet.

Size of rod, Table XXXI, $1\frac{3}{8}$ inches diameter; or, if wood be used, then—

Size of posts (yellow pine), $\frac{45,000}{9,000}$, Table II, column 3=5 square inches area of cross section. A larger post with excess of strength would be used to give better joints.

Size of struts.—Height of the post, 10 feet ÷ by length of bay, 15 feet,=0.67. From Table XXX, column 4, opposite 0.70 in column 1, take factor 0.29. 45,000 multiplied by 0.29=13,050 pounds=maximum stress on each strut. Length of struts$=\sqrt[2]{15^2 \div 10^2}=18$ feet. In Table IV, opposite 18 feet in column 1, the load 16,333 pounds corresponds to a post 8 by 8 inches, which is the minimum size for struts.

Longitudinal stress on beam.—Multiply 45,000 by the factor 0.24 in column 5, Table XXX, corresponding to 0.70 in column 1. The result, 10,800 pounds, is the longitudinal stress on the beam. This divided by the tensile strength, 9,000, gives 1.2 square inches, which multiplied by a factor of safety of 5 gives 6 square inches to be added to the cross section of beam on account of this stress.

For transverse strength of beam.—One-sixth of load, 7,500 pounds uniformly distributed over a clear span of 15 feet, breadth two-thirds of depth, requires, by Formula A, paragraph 13, a beam 6.2 by 9.3 inches=57.66 square inches. Add the area to resist tensile strain on the beam, 6 square inches, as found above, and there results a total cross-sectional area of 63.66 square inches, or, in practice, a beam 7 by 10 inches.

The compression on the upper chord or straining beam is the same as the tension on the lower beam, 10,800 pounds. Its length is 15 feet, and from Table IV a 7 by 7 inch stick is found to be amply strong.

Each truss will then consist of a beam of 45 feet clear span, not less than 7 by 10 inches in cross section; two struts 18 feet long, not less than 7 by 7 inches in cross section; one straining beam, 15 feet long, not less than 7 by 7 inches in cross section; and two rods $1\frac{3}{8}$ inches diameter, or wooden posts of not less than 5 square inches in cross section. In framed wooden structures it is desirable to have one dimension the same in all the pieces that meet at a point, and a considerable excess of material in the structure often results. In this case it will be convenient to take the beam 7 by 10 inches, struts 7 by 7 inches, straining beams 7 by 7 inches, and posts, if of wood, double, each half 3 by 7 inches; or else beams 6 by 11 inches, struts 6 by 8 inches, straining beams 6 by 8 inches, and posts 3 by 7 inches, double.

Figure 232 shows arrangement of a 30-foot queen-post truss for a highway bridge, having about the dimensions above computed.

120. For a light railroad bridge of 20-foot span and 10 feet high, the following dimensions may be used for a king-post truss: Chord 10 by 18 inches, struts 10 by 10 inches, and rods 2¼ inches diameter or better, two rods at each post, each 1⅝ inches diameter, and several inches apart transversely of the bridge.

121. **Inverted forms.**—Both king and queen post trusses may be inverted, figures 216 and 217. All stresses of tension and compression are then reversed. The principles of design are not affected by the change, but wood must be used for posts, and iron is much better for the inclined members and for the lower chords of queen-post trusses. The rods are best made double, one on each side of the beam, and fastened to bolts through the beam at the middle point of its depth. Three or more inverted trusses may be placed beneath a single-track roadway. Of the erect type but two can be used. Double-track bridges are often built with three erect trusses.

122. **Erection of small trusses.**—With a single beam long enough to span the opening the truss may be built in place. The same may be done with a spliced beam, provided it is stiff enough to support its own weight plus that of the men and materials necessary to complete the truss.

The simplest way to get a beam across an opening is to attach a rope to one end and pass it over to the other side; then launch the beam out and haul the front end up with the rope (fig. 222).

Two methods, in which the further bank need not be occupied, are illustrated in figures 223 to 225. In one case an auxiliary beam, and wheels and axle from an ordinary wagon or cart, are used as indicated to place the beam on its abutments. No support between banks is needed. In the other case, two spars are stepped on the bottom as indicated, and their tops lashed together to form a fork, into which the beam is placed. The beam is then pushed across, the spars revolving on their lower ends. The spars must be long enough to reach the higher of the two banks.

Complete trusses may be sprung across by similar means. The application of the second method to an erect king-post truss is illustrated in figure 224. Inverted trusses may be kept upside down until on the abutments and then turned over, provided the chord has sufficient lateral stiffness.

123. **Completion of the bridge.**—The trusses being in position, vertical and parallel to each other and secured, lay floor joists from truss to truss 18 to 30 inches, c. to c., and on them lay a double course of diagonal planking, the upper course at right angles to the lower. Or, lay floor transoms at intervals of about 5 feet, and on them stringers, the latter carrying a single course of cross plank, or two diagonal courses crossed. Planks should be at least 1½ inches thick; if less, lay more courses.

Assuming a live load of 100 pounds per square foot for highway bridges, 3 by 10 inch floor joists spaced 30 inches, c. to c., will be safe up to 12 feet clear width between trusses, or 3 by 12 inches up to 16 feet. For the same load, floor transoms 5 by 10 inches, 5 feet apart, will be safe up to 13 feet clear distance between trusses, or 6 by 12 inches up to 17 feet. On these transoms stringers should be 4 by 6 inches, spaced 18 inches, c. to c., for single, and 30 inches, c. to c., for double planking. (See par. 124, p. 249.)

If the beam of the truss has not been designed to take transverse strains, the floor transoms must be placed at the panel points on the beam, or hung below them, as in figure 232. Such a transom must be strong enough to take the load on one span of the bridge. The stringers, spaced as above, must be increased in size for their increased length. If a queen-post truss, it will be necessary to introduce the diagonal counter braces which may be smaller than the struts. One must run through and the other be made in two pieces so that both counters may be in the same plane (fig. 232).

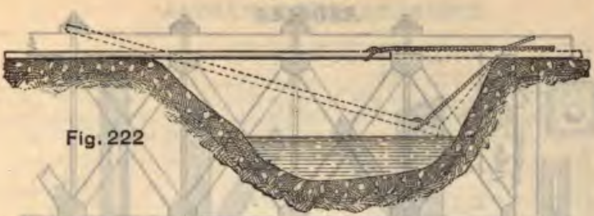


Fig. 222

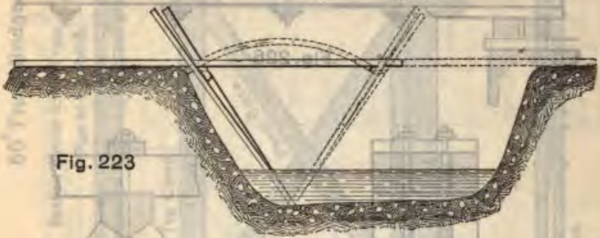


Fig. 223

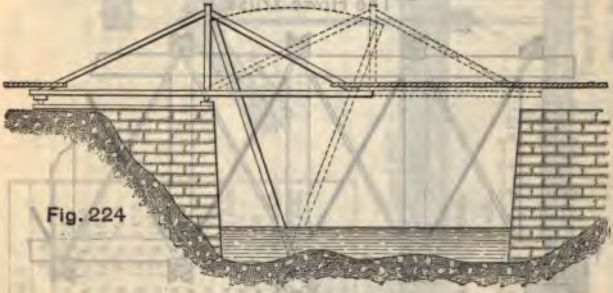


Fig. 224

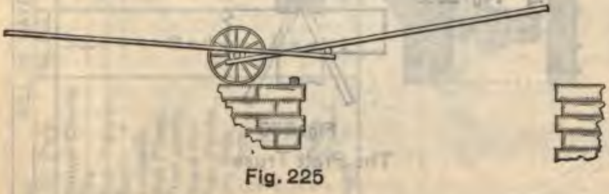


Fig. 225

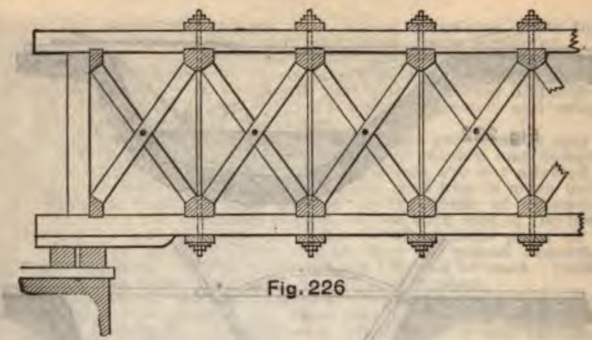


Fig. 226

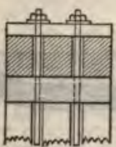


Fig. 227

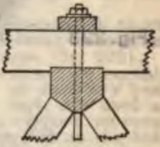


Fig. 228

The Howe Truss

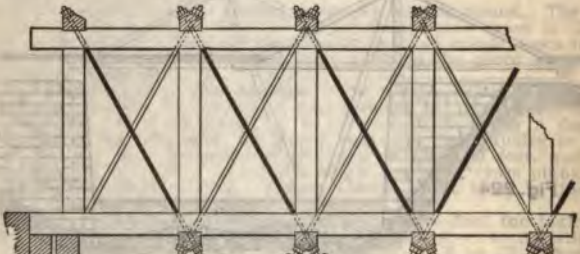


Fig. 229

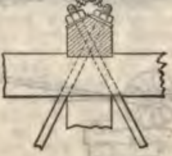


Fig. 230

The Pratt Truss

50′ Truss Bridge.

Section Similar to 30′ Truss. Fig. 232.

BILL OF MATERIALS		
Parts.	No. Pcs.	Size.
Bottom Chords.	10	4″ x 12″ x 23′
Top "	10	4″ x 12″ x 18′6
End Braces.	4	12″ x 12″ x 16′6
Panel "	8	6″ x 8″ x 16′
Transoms.	2	10″ x 12″ x 23′6
Wall Plates.	2	10″ x 12″ x 18′6
Floor Joists.	32	3″ x 8″ x 14′
Guard Rail.	6	6″ x 6″ x 18′
Floor Planks.	75	2″ x 8″ x 16′
Iron Rods	6	1½″ x 12″ THREAD ON BOTH ENDS.
" Bolts.	8	1″ x 30″ "
" "	4	¾″ x 30″ "
" "	280	⅝″ x 12″ HEAD & NUT.
" "	4	⅝″ x 18″ THREAD ON BOTH ENDS.
" Plates.	4	12″ x 30″ x ¾″
" Washers.	8	6″ x 6″ x ½″
Angle "	16	Pattern.

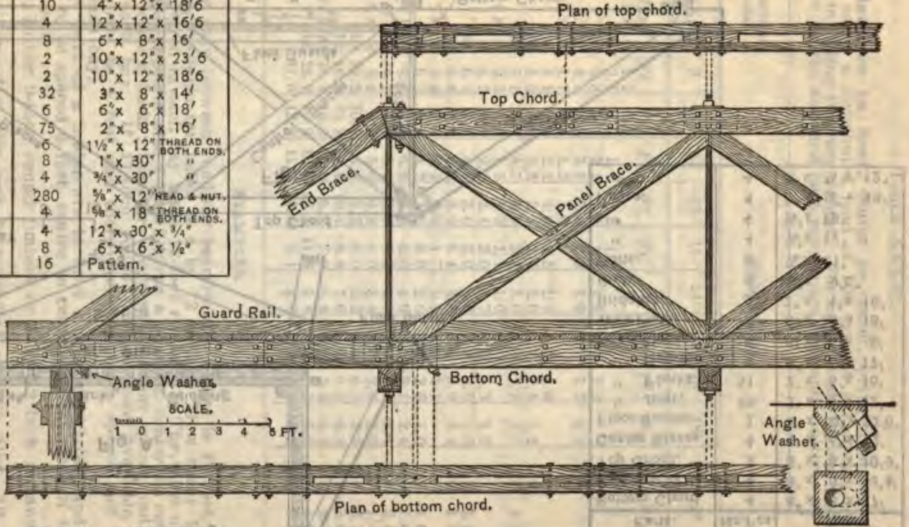


Fig. 231

30 Ft. Truss Bridge

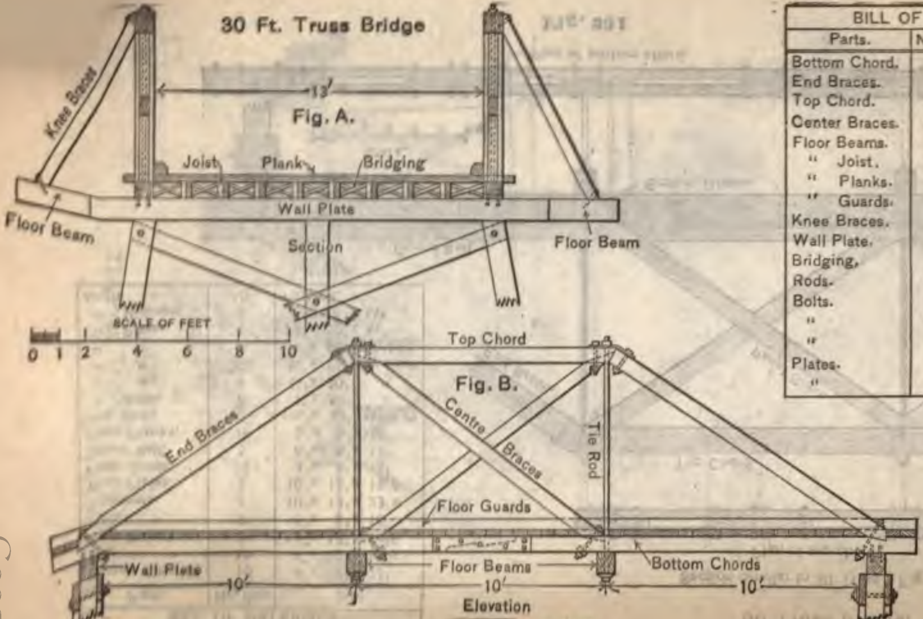


Fig. 232

BILL OF MATERIALS.		
Parts.	No. Pcs.	Size.
Bottom Chord.	4	8″ x 8″ x 17′
End Braces.	4	8″ x 8″ x 13′4″
Top Chord.	2	8″ x 8″ x 10′9″
Center Braces.	4	4″ x 6″ x 12′
Floor Beams.	2	8″ x 10″ x 23′6″
" Joist.	24	3″ x 8″ x 12′
" Planks.	51	2″ x 8″ x 16′
" Guards.	4	6″ x 6″ x 17′
Knee Braces.	4	6″ x 6″ x 8′
Wall Plate.	2	8″ x 10″ x 18′
Bridging.	9	2″ x 4″ x 16′
Rods.	4	1⅜″ x 9′6″
Bolts.	8	⅞″ x 21″
"	4	⅞″ x 12″
"	4	⅞″ x 10″
Plates.	4	8″ x ½″ x 48″
"	4	8″ x ¾″ x 12″

TABLE XXXII.

124. **Distance in feet,** center to center, between stringers or beams to carry a distributed load of 100 pounds per square foot of roadway, including its own weight. For other loads divide the tabular number by the assumed load per square foot and multiply by 100.

Round.	Rectangular.	Span in feet.											
D	*b* x *d*	9	10	11	12	13	14	15	16	18	20	22	24
Ins.	*Ins.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*
5	2 x 6	1.2	1.0										
6	8	2.1	1.7	1.4	1.2	1.0							
7	10	3.3	2.7	2.2	1.8	1.5	1.3	1.1	1.0				
	12	4.7	3.8	3.1	2.6	2.2	1.9	1.7	1.5	1.2	1.0		
	3 x 6	1.7	1.4	1.2	1.0								
	8	3.1	2.5	2.1	1.8	1.5	1.3	1.1	1.0				
8	10	4.9	4.0	3.3	2.8	2.3	2.0	1.7	1.5	1.2	1.0		
9	12	7.1	5.7	4.7	4.0	3.4	3.0	2.5	2.2	1.7	1.4	1.2	1.0
	4 x 6	2.3	1.9	1.5	1.3	1.1	1.0						
	8	4.2	3.4	2.8	2.4	2.0	1.7	1.5	1.3	1.0			
	10	6.6	5.4	4.4	3.6	3.0	2.6	2.2	2.0	1.6	1.3	1.1	1.0
	12	9.4	7.6	6.2	5.2	4.4	3.8	3.4	3.0	2.4	1.9	1 5	1.3
	6 x 6	3.4	2.8	2.4	2.0	1.7	1.4	1.2	1.1				
	8	6.2	5.0	4.2	3.6	3.0	2.6	2.2	2.0	1.6	1.2	1.0	
10	10	9.8	8.0	6.6	5.6	4.6	4.0	3.5	3.1	2.4	2.0	1.6	1.3
	12	14.2	11.4	9.4	8.0	6.8	6.0	5.0	4.4	3.4	2.6	2.4	2.0
	8 x 8	8.4	6.8	5.6	4.8	4.0	3.4	3.0	2.6	2.0	1.7	1.4	1.1
11	10	13.2	10.6	8.8	7.2	6.0	5.2	4.4	4.0	3.2	2.6	2.2	2.0
	12	18.8	15.2	12.4	10.4	8.8	7.6	6.6	6.0	4.8	3.8	3.0	2.6
	10 x 10	16.4	13.3	11.0	9.2	7.9	6.8	5.9	5.2	4.1	3.3	2.7	2.3
	12	23.7	19.2	15.8	13.3	11.3	9.8	8.5	7.5	5.9	4.6	4.0	3.3
12		17.0	13.8	11.4	9.6	8.1	7.0	6.1	5.4	4.2	3.4	2.8	2.4

EXAMPLES.

(1) The span between roadway bearers of a bridge is 16 feet, and the timber available for balks is 4 by 12 inches. How many balks will be required in each bay for a 12-foot roadway? The table under span 16 and opposite size 4 by 12 gives a spacing, center to center, of 3 feet between balks; therefore there will be four spaces and five balks in each bay. If 11-inch round timbers were available, the spacing would be 4 feet and there would be three spaces and four balks in each bay.

(2) The bays of a bridge are to have a span of 12 feet and the balks are to be spaced 4 feet, center to center. What sizes of balks may be used?

Answer. Either 9-inch round timbers or 3 by 12 inch rectangular beams.

(3) The cap of a pile bent is supported on two piles, 10 feet center to center, and the bents are spaced 15 feet center to center. What size of cap is required? Opposite "15.2 feet" in column "10 feet" is found the required size, 8 by 12 inches, for the cap. Intermediate sizes, spans, and spaces may be found by simple interpolation.

125. Wagons and Artillery carriages bring concentrated wheel loads on the bridge, and for such loads the foregoing table is not applicable.

The following assumptions simplify the problem, give safe results, and are in accord with the usual conditions. The balks are assumed to be so spaced that the load of any one wheel is transmitted by the flooring to at least two balks.

When the spans of the balks is less than twice the length of wheel base of the carriage the greatest strain occurs when the heaviest wheel loads are at the middle of the span. When the span of the balks is more than twice the length of wheel base of the carriage each wheel is supposed to have a load equal to the greatest wheel load of the carriage, and the strain is greatest when the center of the carriage is at the middle of the span.

For Light Artillery and Army wagons the heaviest wheel load is 1,750 pounds. Add one-half the weight of the flooring carried by two balks and 2,000 pounds may be taken as the concentrated load on two balks, giving 1,000 pounds on one balk, applied at the middle point if the span is less than twice the wheel base, and applied at two points 6 feet apart and equidistant from the middle point if the span is more than twice the wheel base. In the same way 2,000 pounds may be taken as the concentrated load on one balk for siege Artillery applied in like manner with a wheel base of 8 feet.

Table XXXIII.

126. Sizes of round and rectangular balks and maximum safe spans in feet for wagons and Artillery.

Round.	Rectangular.	Maximum safe spans in feet for 4 or more balks.	
D	*b* x *d*	Wagons and light artillery.	Siege artillery.
Inches.	*Inches.*		
5	2 x 6	4.8	....
6	8	11.2	5.6
7	10	12.6	6.6
	12	15.6	9.6
	3 x 6	7.2	3.6
8	8	12.6	6.4
	10	16.0	10.0
9	12	20.4	14.4
	4 x 6	9.6	4.8
	8	14.5	8.5
	10	19.3	13.3
	12	25.2	17.6
	6 x 6	13.2	7.2
	8	18.8	12.8
10	10	26.0	18.0
	12	34.8	22.4
	8 x 8	23.0	16.5
11	10	32.5	21.2
	12	44.4	27.2
12	10 x 10	39.3	24.6
	12	52.0	32.0

The flooring must be strong enough to transmit its load to the *and its thickness* will depend on the load and on the spacing of the balks. Concentrated wheel loads will cause the greatest stresses, and these may be taken as 1,600 pounds on one wheel for wagons and light artillery and 3,200 pounds on one wheel for siege artillery.

TABLE XXXIV.

128. **Thickness of flooring in inches to carry wagons and artillery for varying distances between balks.**

Distance between balks (s. in feet).	Thickness of flooring.			
	Wagons and light artillery.		Siege artillery.	
	Plank. d	Poles. D	Plank. d'	Poles. D'
	Inches.	*Inches.*	*Inches.*	*Inches.*
1.0	1.4	2.3	2.0	3.5
1.5	1.7	3.2	2.4	4.0
2.0	2.0	3.5	2.8	4.4
2.5	2.2	3.8	3.2	4.8
3.0	2.4	4.0	3.6	5.1
3.5	2.6	4.3	3.7	5.4
4.0	2.8	4.5	4.0	5.6

For a footbridge, the thickness of flooring in inches may be safely taken as one-half the span between balks in feet, or $d=\frac{1}{2}s$.

129. Figures 245–247, reproduced by permission from Plate III, War Department Document No. 273, 1906, show interesting features of field bridges built by the Japanese during the Manchurian war. The use of railroad iron and the very general employment of iron dogs for fastenings are noticeable.

130. **The Fink truss** (figs. 220 and 221) is a superposition of king-post trusses. It is practicable in the inverted form only, but may be elevated on posts shown in figure 221. In this case all the posts are best made of equal length to form the supports of the roadway. A primary post supports the middle, which becomes a central support for two secondary trusses, and the two points supported by the secondary posts *BB*, become in turn supports for four tertiary trusses *CC*, and so on. The stresses in the primary truss are worked out as in paragraph 118. The stresses for secondary and tertiary trusses are worked out in the same way, taking one-half the load on the bridge for the secondaries and one-fourth for the tertiaries. The details of fastenings are shown in figure 220.

131. **The Howe truss** (fig. 226).—This useful form consists of two parallel chords, usually continuous built-up beams, divided by posts in tension into equal panels, each of which has diagonals in compression. The upper chord is in compression, the lower in tension. Each chord is made up of three or more parallel timbers of uniform size, with lengths adapted to properly distribute the splices. The timbers are separated by the diameter of the largest rods, so that the latter may pass through the spaces. The main braces are one less in number than the pieces in the chord and abut, top and bottom, against angle blocks of metal or hard wood, triangular in section and extending entirely across the chord. Against these blocks the counter-braces, one less in number than the main braces, also abut. The ver-

SPECIAL FORMS.

141. Figures 233 to 235 show a **double bowstring truss** which can be constructed of common boards and nails, or even with boards and pins. It does not possess advantages warranting its adoption when materials for standard trusses can be procured with equal convenience.

Lay out the truss by drawing on the ground two arcs of circles corresponding to the inner surfaces of the chords with a radius two and one-half times the length of the truss. Along these arcs drive stakes, around which bend the boards and nail securely to each other but not to the stakes. The boards are 1 by 12 inches; the upper chord has five layers, the lower six. The boards break butts and are nailed about every 4 inches with 10*d.* nails; bolts or 6-inch spikes should also be driven through the lower chord at intervals of 6 to 12 inches. Bolts ½ inch diameter, set up tight, are the best.

The truss is divided into 10 panels by posts of 2 by 12 inch plank and tie-rods of 1¼-inch iron at each panel point. Main and counter braces of 2 by 12 inch plank are used in all the panels except at the ends, which are filled solid for about 4½ feet. The chords are nailed to the blocks and the whole bolted through from top to bottom with five or six bolts at each end.

It will be found advantageous to cover the boards with a mixture of pitch and tar before they are nailed together to increase friction between them.

TABLE XXXVI.

142. **Bill of materials** required for **two double bowstring plank trusses** for each foot of span:

Lumber, 1 by 12 inches, 30 feet b. m.
Lumber, 2 by 12 inches, 12 feet b. m.
Lumber, 2 by 8 inches, 9 feet b. m.
Nails, 10*d.*, 2.5 pounds.
Nails, 20*d.*, 1 pound.
Spikes, 6-inch, 1 pound.
Iron rods, 1¼ inches in diameter, 10 pounds.
Iron bolts, ½ by 6 inches, 3 pounds.

The above quantities are approximate only, but suffice as a basis of estimate. The truss built as described will carry a live load of 500 pounds per foot on a span of 60 feet, and proportionally more for shorter spans.

The roadway can best be carried on the top chord. The transoms should be at the posts. The middle one and the two on each side of it may rest directly on the chord. Those at three, four, and five tenths of the span from the middle on each side should be blocked up from the chord, 0.005, 0.010, and 0.018 of the span, respectively. This arrangement gives a camber of one thirty-fifth of the span. With the roadway on top, the trusses must be cross-braced with 2-inch plank as indicated in figure 235.

If it is necessary to keep the trusses up, as, for example, to get above high water, the roadway may be carried between or below them. If between, bolt the transoms to the posts and extend them beyond the trusses far enough to receive steadying braces (fig. 232). The end transoms may rest on the abutments and the next ones to them on the lower chord. Stretch a line between the tops of the two which rest on the chord, raise this line at the middle post by the amount of camber desired, and mark on each intermediate post the point where the line crosses it, which will be the top of the transom on that post.

By supporting the ends of the truss on posts or piers, the roadway may be carried at or below the bottom. The middle transom should be held firmly against the bottom of the chord. The next one on each side will be bolted to the chord through a block 0.006 of the

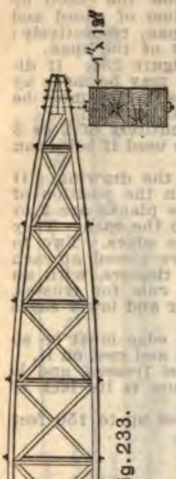


Fig. 233.

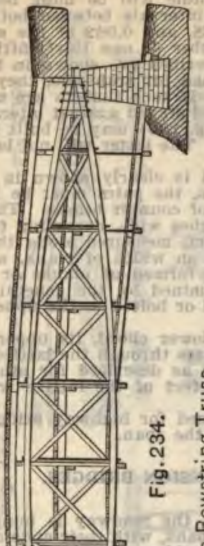


Fig. 234.
Double Bowstring Truss

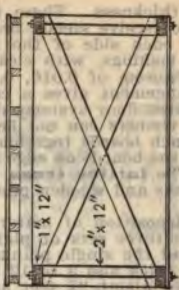


Fig. 235.

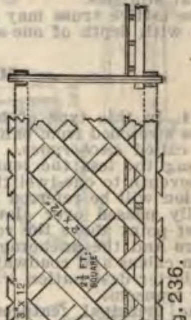


Fig. 236.
Lattice Truss

span in thickness. These three transoms should extend beyond the trusses to receive steady braces. The second, third, and fourth transoms on each side of the middle will be hung below the chord by bolts or lashings, with clear intervals between bottom of chord and top of transom of 0.016, 0.038, and 0.062 of the span, respectively; this arrangement gives a camber of one thirty-fifth of the span.

The three floor systems described are shown in figure 234. If dimension timbers can not be had for transoms, they may be made by nailing inch boards together. If such timbers are used, they must be set with the boards on edge and stayed against lateral bending.

143. The **lattice truss** (fig. 236) may be built entirely of 2 or 3 inch planks and wooden pins. The latter will not be used if bolts can be had.

The disposition of material is clearly shown in the drawing. If there are three sets of planks, the pairs must be in the position of braces and the single planks of counter braces. The planks are 2 or 3 inches thick and 9 to 12 inches wide, according to the span. They are placed about 2½ feet apart, measured along the edges. Two to four pins or bolts, depending on width of plank, are placed at each intersection. The chords are formed of planks or timbers, with an aggregate cross section determined by the general rule for trusses, paragraph 132 and are pinned or bolted to the upper and lower edges of the lattice as indicated.

If the roadway be on the lower chord, its upper edge must be so placed that the transom can pass through the lattice and rest on it.

The *lateral bracing* may be as described for other trusses, and is *very important*, as a chief defect of the lattice truss is its lack of lateral stiffness.

The lattice truss may be used for highway bridges up to 150 feet span with depth of one-sixth the span.

SUSPENSION BRIDGES.

144. In this type of bridge the roadway is hung to two or more cables stretched from bank to bank, with their ends attached to fastenings called *anchorages*. The cables are allowed to sag; the greater the sag the less the tension, but the more the vibration. A sag of one-seventh to one-twelfth the span is the best for field bridges. This fraction will be referred to as the ratio of deflection. The cables are usually passed over elevated supports called *towers*, to keep their lowest point above the roadway. The parts of the cable between the towers and the anchorages are called *backstays*. The connection between cables and roadway is by rods called *suspenders, ties*, or *slings*. The latter designation will be used. There is a sling at each end of each transom.

The principal features of a suspension bridge are indicated in figure 237.

145. In military field operations the suspension bridge is best adapted to light loads or long spans or the two combined. The construction of a suspension bridge for heavy traffic will usually be impracticable with field equipment. When materials for nonfloating bridge must be carried with a column, the suspension type is best, because it is lightest for a given capacity and its materials are divisible into small portions for transportation.

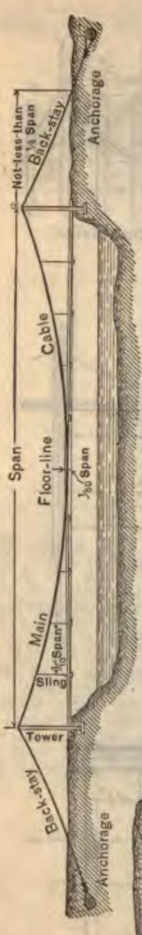


Fig. 237

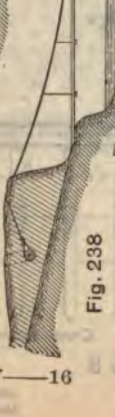


Fig. 238

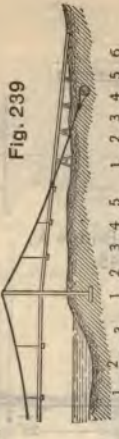


Fig. 239

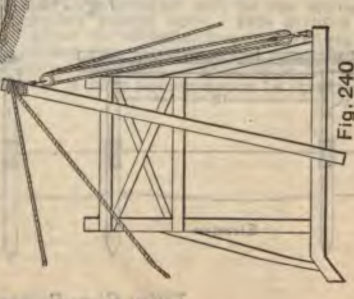


Fig. 240

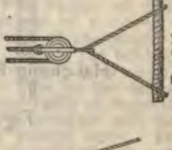
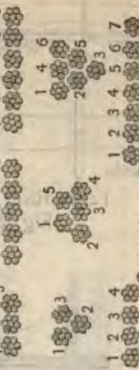


Fig. 241



Grouping of Cables
Fig. 242

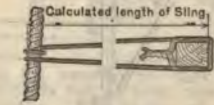


Fig. 243

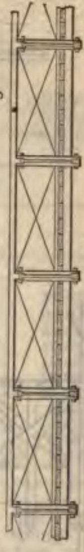
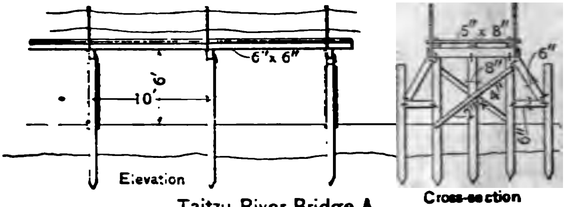
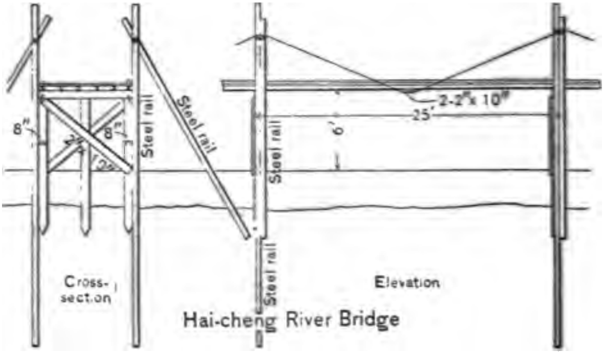


Fig. 244
Suspension Bridge

Japanese Field Bridges

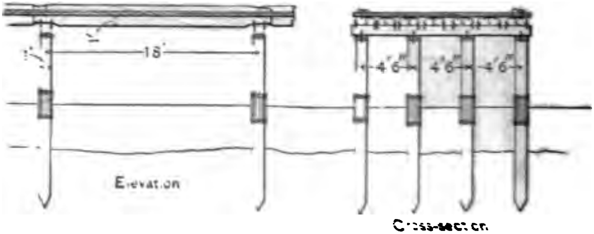


Taitzu River Bridge A.
Fig. 245.



Hai-cheng River Bridge

Fig. 246.



Taitzu River Bridge B.
Fig. 247.

JOSEPH E. KUHN,
MAJOR OF ENGINEERS.

TABLE XXXVII.

146. **Data** for calculating **main cables** for **suspension bridges**; authority, Trautwine:

Deflection in parts of the chord.	Length of main cable between towers in parts of chord.	Tension on all the main cables at either tower in parts of entire suspended weight of bridge and its load.	Tension at the center of all main cables in parts of entire weight.	Angle of direction of cables at piers= A=angle made by cable with horizontal.	Radius= deflection multiplied by—
1	2	3	4	5	6
				° ′	
$\frac{1}{15}$	1.012	1.94	1.870	14 55	28.625
$\frac{1}{14}$	1.013	1.82	1.740	15 57	25.000
$\frac{1}{13}$	1.016	1.70	1.620	17 6	21.625
$\frac{1}{12}$	1.018	1.57	1.490	18 33	18.500
$\frac{1}{11}$	1.022	1.46	1.370	19 59	15.625
$\frac{1}{10}$	1.026	1.35	1.250	21 48	13.000
$\frac{1}{9}$	1.033	1.23	1.120	23 58	10.625
$\frac{1}{8}$	1.041	1.12	1.000	26 33	8.500
$\frac{1}{7}$	1.053	1.01	.881	29 45	6.625
$\frac{1}{6}$	1.070	.90	.750	33 41	5.000
$\frac{1}{5}$	1.098	.80	.625	38 40	3.625

The above table is based on the assumption that the curve of the main cables is a parabola, which is not strictly correct, though near enough for all practical purposes. For ratios of deflection in the table, the curve is practically the segment of a circle, the radius of which may be taken from the sixth column of the table.

147. Having the *span* and total *live load* on the bridge, to determine the total area of the cables, compute the dead load as in paragraph 4; add the live load to it and multiply the sum by the factor in column 3 of the table corresponding to the adopted ratio of deflection. Multiply this result by the factor of safety. The product will be the ultimate strength which all the cables together should have. This divided by the number of cables to be used gives the ultimate tensile strength of each one, and its size and composition may be determined from Tables X, XI, or XXXVIII. A lower factor of safety is admissible for wire than for most other materials, as it is very homogeneous in structure.

TABLE XXXVIII.

148. **Composition of main cables of suspension bridges:** factor of safety [illegible]; live load 200 pounds per linear foot; dead load 100 pounds per linear foot; ratio of deflection 1/7.

Span.	Number of strands of 1-inch wire rope in main cables.		Number of parallel steel wires in main cables.						
	Iron.	Steel.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	No. 11.	No. 12.
Feet.									
45	4	2	14	18	20	24	28	34	42
60	4	2	18	22	24	30	36	46	56
75	4	2	22	26	32	38	44	56	70
90	4	2	26	32	38	44	54	70	84
105	4	4	32	38	44	52	64	80	98
120	6	4	36	42	50	60	72	90	112
135	6	4	40	48	58	68	80	100	122
150	8	4	46	54	62	74	90	112	140
165	8	4	50	58	68	82	100	124	154
180	8	4	54	64	76	90	110	138	170
195	10	6	58	70	80	98	118	146	182

For any other ratio of deflection, less than 1/7, increase the tabular numbers by 1/9 for each unit of the denominator above 7. For other loads, greater or less, increase or decrease the tabular numbers pro rata.

Example: How many No. 8 steel wires are required for the main cables of a bridge of 105 feet span, ratio of deflection 1/10, and a gross load, live and dead, of 600 pounds per linear foot?

From the table, 105 feet span, No. 8 steel wire, take 44. Add for change of ratio of deflection from 1/7 to 1/10, 3/9 or 1/3, making 58⅔. For change from 300 to 600 pounds load multiply by 2, making 117⅓. Take next even number above, 118, which is the number required. If two cables are used, make each of 59 wires.

149. **Tension on backstays.** If the cables are free to move on the tops of the towers, the tension on the backstays will always be the same as that on the cable. In this case the towers are stationary and should be massive.

If the cables are fixed to the tops of the towers, the tension on the backstays will be equal to, less than, or greater than the tension on the cable, accordingly as the slope of the backstay at the top of the tower is equal to, less than, or greater than the slope of the cable. It is usually best to make these slopes equal.

150. **Stresses on the towers.** When the slopes of cables and backstays are equal, the stresses on each tower will be vertical and equal to the entire weight and load of the clear span.

When these slopes are unequal the pressure on the towers will be oblique. If the slope of the backstay is *less* than that of the cable, the tower will tend to revolve or slide *toward* the anchorage, and the pressure on each tower will be less than the weight and load of clear span. If the slope of the backstay is *greater* than that of the cable, the towers will tend to revolve or slide *toward each other*, and the pressure on each will be *greater* than the weight and load of clear

When possible, the horizontal distance from the foot of a tower to the corresponding backstay should be one-fourth of the clear span or greater. In such case the tension on the backstay will not exceed that on the cable, and the pressure on the tower will not exceed the total weight and load of the clear span.

151. **Making cables.**—Three-quarter inch wire rope weighing 92 pounds to the 100 feet can usually be carried in lengths sufficient for practicable suspension spans, and will be the most convenient form.

If ordinary wire must be used, cables can be made by stretching wires—seven is a good number—close together and under equal strain and binding them together at intervals of a foot with marline or wire. If short cables are required, time may be saved by making one of two or more times the length and cutting it in pieces.

152. **Anchorages.**—These are of prime importance and must be secure and as rigid as possible. Their character will often be determined by accidents of the site. When the stumps of large trees are available they will usually be chosen. Ledge rock or large bowlders are the best, but require care and some skill in making the fastenings. Heavy staples leaded or wedged into holes drilled into the rock will usually be most convenient. If Portland cement can be had, a grouting will hold the iron firmly after it is set. See also description of *deadman,* paragraph 50.

153. **Towers.**—Large trees will be used if available, otherwise trestles of timber; see paragraph 64. With high banks it may be feasible to start the cables from the surface of the ground or a short distance above it and provide approaches to a depressed roadway as indicated in figure 238. For low banks the roadway must be kept above the grade as in figure 239, the backstay carrying it beyond the tower.

The towers must be high enough to bring the supports of the cables called *saddles* above the level of the roadway at the tower by the desired deflection plus one-fiftieth of the span; see paragraph 142.

154. **Placing cables** may be done by hauling across tops of towers, or by laying out cable from one anchorage to the other and raising the bights to the tops of the towers by shear poles (fig. 240). The cable should hang in a bridle (fig. 241). In the former case the cable will usually have to be slushed, which is an inconvenience in the subsequent operations.

The saddle should be a smooth, firm bearing, sufficient to take all the cables side by side. In binding the small cables together to form a larger one, adopt the most compact arrangement, the outside strands as they lie side by side on the saddle generally going into the upper half and the central ones into the lower half of the complete cable; and note carefully that the arrangement is identical at all points, so that the strands do not ride or cross each other anywhere. The bunching should include the backstays, but need not be carried across the towers, leaving the strands flat on the saddles. Several groupings are illustrated in figure 242.

In either method of placing, the cables should be permanently fastened at one end and be connected with the anchorage at the other end by a luff tackle, to be used in adjusting the length. When the adjustment is finished, this end is made permanently fast and the tackle removed.

155. In clear weather the *dip of the cables* may be determined by direct observation. Fix the elevation of the bottom of the transom at each tower, and above it, a distance equal to one-fiftieth of the span, fasten a batten or stretch a line horizontally. Adjust the cable so that its lowest point ranges between the battens or lines.

If wind, fog, or darkness prevents this operation, lay the cables out side by side before they are hoisted up, and put them under as uniform strain as possible. Mark each with a few turns of soft wire, as *near the point* where it will rest on the saddles as can be computed. *The distance* between marks on all the cables must be exactly the same. When the cables are in place, adjust them so that these marks coincide, and the deflections will be sufficiently uniform to develop the combined strength of the strands.

156. **Lengths of slings** depend upon the curve of the main cables and the camber of the roadway. The latter must be liberal in field suspension bridges. The cables will stretch, especially those made of wire rope, and the anchorages and tower footings will give more or less. One-fiftieth of the span will usually be enough.

The lengths of slings are reckoned from the cable to the lower side of the transoms in a vertical line (fig. 243). They must be determined in advance and adhered to during construction, regardless of the appearance of the bridge when partially done. When the roadway is completed the distortion will disappear.

From the following table the lengths of slings at intervals of one-twentieth of the span, starting from the middle, may be readily determined.

TABLE XXXIX.

157. From the line corresponding to the ratio of deflection take out the successive factors and multiply each by the span in feet. The results will be the lengths of slings in feet at the corresponding points on *each side* of the middle.

As the length of the middle sling is 0, the middle transom will rest directly on the cable. If transoms are not of same depth, allowance must be made for the difference.

Note especially that these tabular lengths do not include any fastenings. Be sure to add enough for that purpose, but when the fastenings are made see to it that the distance from cable to bottom of transom is precisely the corresponding tabular distance.

In this table allowance is made for a camber of one-fiftieth of the span in two straight lines from the ends to the middle.

Ratio of deflection.	Distance of sling from center in parts of span.								
	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45
$\frac{1}{6}$	0.0036	0.0107	0.0209	0.0346	0.0516	0.0720	0.0953	0.1267	0.1529
$\frac{1}{7}$	.0034	.0097	.0188	.0308	.0456	.0634	.0840	.1074	.1336
$\frac{1}{8}$	.0032	.0090	.0172	.0280	.0412	.0570	.0752	.0960	.1192
$\frac{1}{9}$	.0032	.0084	.0160	.0258	.0377	.0519	.0684	.0871	.1080
$\frac{1}{10}$	.0030	.0080	.0150	.0240	.0350	.0480	.0630	.0800	.0990
$\frac{1}{11}$	.0029	.0076	.0142	.0226	.0327	.0447	.0585	.0742	.0916
$\frac{1}{12}$	.0028	.0073	.0135	.0214	.0308	.0420	.0548	.0693	.0855
$\frac{1}{13}$	.0028	.0071	.0129	.0203	.0292	.0397	.0517	.0652	.0803
$\frac{1}{14}$	.0027	.0069	.0124	.0194	.0278	.0377	.0490	.0617	.0759
$\frac{1}{15}$	.0027	.0067	.0120	.0187	.0267	.0360	.0467	.0587	.0720

158. **Form and strength of slings.**—Wire will usually be the material used. The load on each sling may be taken as the total load, live and dead, divided by the number of slings. It is really somewhat less. Knowing the size of wire on hand, divide the number of wires of that size which are used or would be required for the main cables, Table XXXVIII, by the number of slings. The quotient will be the *number of wires* of that size which should be in each sling.

The slings may be made single and fastened at top and bottom by *loops around cable* and transom, or, more conveniently, made of half *size and double length*, taking a round turn on the cable at the middle, bringing the two ends around the transom in opposite directions and twisting them together on top of it (fig. 243).

A very useful attachment of wire to wood is made by means of a nail or spike partly driven beside the wire and the head bent over so as to embrace the wire like a staple. A staple, if available, is of course better.

159. **Construction** of the **roadway.**—A transom will hang in each pair of slings. On the transoms lay longitudinal stringers of number and size determined by the load, length of bay, and materials available, see paragraph 8. The stringers should be long and should lap 3 feet or more and be firmly lashed or spiked together; the lap need not be on a transom, but is better near one. On the stringers the planks are placed and spiked down or held by side rails.

Place the first pair of slings on the cables, taking the turns loosely so that they will slide. Sling the first transom so that its bottom shall be the calculated distance from the cable measured along the sling. Fasten two stringers to it and push it out, the slings sliding on the cables, until the transom is in its proper position and the slings vertical. Crimp the turns at the top and place the second pair of slings and transom in the same way. Follow up with stringers and planks.

160. A **hand rail** should be provided, and a screen on each side of brush or other light materials will be useful.

161. Suspension bridges change their shape vertically and laterally from the live load and from wind pressure. Vertical distortions are referred to as *undulations* and lateral ones as *oscillations.* Undulations result principally from changes in the moving load and to a less extent from the vertical component of wind pressure. Oscillations are caused principally by horizontal wind pressures and in a lesser degree by the moving load. Both must be kept within small limits. Undulations may be reduced by making the handrail or balustrade fairly high and trussing it lightly (fig 244); also by using deep stringers well lapped and fastened so as to be practically continuous.

Oscillations may be reduced by placing the cables farther apart at the towers and drawing them in at the center. This will affect the length of slings, but not seriously. Also by a lateral truss under the roadway, using the transoms for posts and adding diagonal ties or braces. (See par. 129.)

Both undulations and oscillations may be controlled by guys attached to the roadway and carried inshore and up and down stream to secure fastenings.

162. **Railway bridges.**—With proper assumptions as to loads (see par. 5), the foregoing rules for designing and proportioning the several types of bridges will give safe structures for railway traffic. (See also pars. 43, 67, and 120 and Tables XX and XXXV.

A railroad bridge should not be built on an incline if it can be avoided. The approaches at each end should be straight and nearly level for a distance equal to at least twice the maximum train length.

Foundations must be especially unyielding, as settlement is more troublesome than in other bridges.

For a single-track standard-gauge railway bridge, the clear width between trusses or girders should be 14 feet. In double-track bridges the distance from c. to c. of tracks must not be less than 13 feet. No part of the truss may be less than 7 feet from the center of the nearest track, at a height exceeding 1 foot above the rail.

The clear headroom must be 21 feet above the base of the rail for a width of 6 feet over each track.

Stringers are put under the rails and are best made in two or more pieces long enough to span two bays and breaking joints. The pieces are separated about 2 inches by blocks and well bolted together. Ties are placed 18 to 24 inches c. to c., and every third *or fourth one* should be spiked to the stringers. A guardrail should *be placed along* the ends of the ties, and it is better to place unde *the tie a lighter* stringer and bolt the guardrails to it.

PART III.

ROADS.

PART III—ROADS.

1. **Military road making** will, in most cases, be a question of repairing existing roads to make them temporarily passable, the work to be done in the shortest possible time. Labor is likely to be plentiful, though not the most efficient. Machinery and transportation will be scarce. Materials actually on the line or very near it must be used. To decide upon the best plan under such circumstances, and to carry it out most successfully, it will be helpful to have a general knowledge of the conditions which make good roads and those which make bad ones, and of the best methods of converting the latter into the former, or, in other words, of the principles of road construction. These principles are the same for all roads, though the practice resulting from their application may differ in military roads from that considered best for civil roads.

2. **The supporting power** of cohesive compacted earth, moist but not wet, is sufficient to bear without objectionable indentation the weights on hoofs and wheels which result from ordinary highway traffic. The supporting power of the same earth when thoroughly wet is only about one-thirtieth as much, and is not sufficient to carry the weights on hoofs and wheels until the wagons have sunk to their axles and the animals to their bellies, when traffic becomes impossible. Between these extremes lie many gradations of good and bad roads.

3. Civil roads are also rated as bad when the surface, though hard, is rough, as when there are projecting bowlders or ledges of rock crossing the road, or stumps or roots in the way; and also when any of the grades exceed the limit at which a team can pull its own load.

As to roughness, its principal effect is to increase the wear and tear of vehicles and the discomfort of passengers, and to prevent a faster gait than a walk; hence it is of secondary importance for military traffic. As to gradients, it is to be remembered that army transportation is always in trains, so that teams can be doubled when necessary, and also that there is usually an ample supply of labor in reach so that loads can be broken. Within the limits of possible wheel transportation, steep gradients alone may delay military traffic, but can not stop it.

Extensive work for reduction of grades will rarely be worth while so long as the prevailing natural grades do not exceed 3°, and the maximum are short and not steeper than 6°. Rolling country, classed as decidedly rough, will be found within these limits.

For long grades, as in mountain roads, considerable work may be profitably expended in keeping prevailing grades within 2°, with a maximum of not more than 4° on short ones.

4. The **paramount question** to be dealt with will be the supporting power of the roadbed as affected by water. This supporting power will be a maximum when the soil is sufficiently damp to compact well and yet not wet enough to yield considerably under the pressure. It is not desirable to remove all the moisture from the soil, because if this is done it loses its compacting power, and any particles dislodged from cohesion to adjacent ones remain on the surface in a friable condition, refusing to reunite under pressure until moisture is supplied.

The **supporting power of wet earth** may be increased in two *ways: First, by* removing the surplus water and keeping it out, and

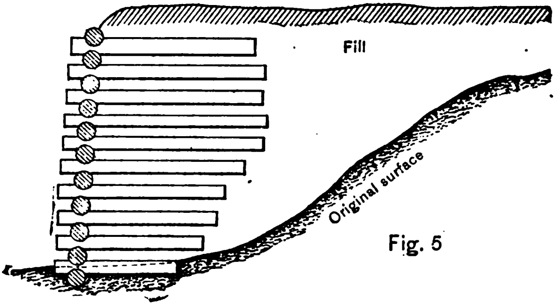


Fig. 5

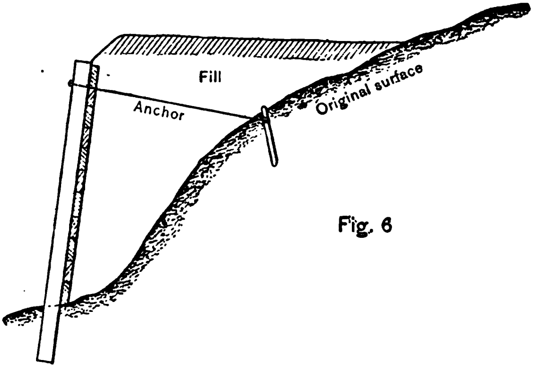


Fig. 6

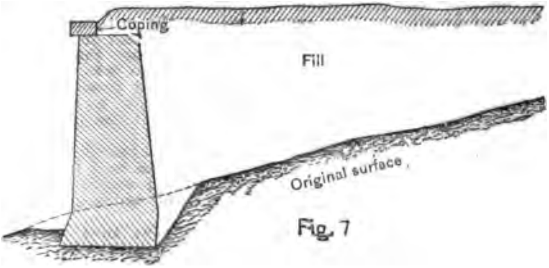


Fig. 7

the crib may be omitted and the front one held in place by logs running back into the bank (fig. 5). These logs may be replaced by cables made fast to posts. This construction can best be applied when the cables can be carried back to solid ground (fig. 6).

Vertical posts, with their feet let well into the ground and the tops anchored by either of the above methods may support horizontal planks, which in turn support the fill (fig. 6). Construction in timber for this purpose are usually called *bulkheads.*

Masonry retaining walls should have an average thickness of four-tenths to five-tenths their height above the ground, the former for good rubble laid in cement mortar, the latter for dry rubble. The thickness may be the same from top to bottom, or it may be greater at the bottom and less at the top, the average remaining the same. If the wall is high, the latter section should be adopted, as it requires less material for a given height and strength. Dry rubble must be of large stones fairly well fitted together. Whether with or without mortar, it is desirable to avoid through horizontal joints. Some stones should be so placed as to lie partly in two adjacent courses, acting as dowels to prevent the upper part of the wall from sliding along the joint between the two courses. Walls should be built with a batter on the front from ½ to 1 inch to the foot, as they will always move out a little at the top, and if originally built plumb, will then overhang and look unsafe.

Especial attention must be given to the **character** of the **foundation at the foot** of the front face. A trench must be excavated deep enough to get to a firm bearing at this point. The front of this trench should be kept as solid as possible to form a support to the wall against sliding on its base (fig. 7). If the wall yields to the pressure against it, it will most probably revolve around the toe, and its entire weight will come on the front edge of the foundation trench, which must be able to support the weight or the wall will overturn.

17. **Culverts.**—An inclosed conduit for passing drainage under a road is called a **culvert.** The distinction between bridges and culverts is vague. Some small bridges are often called culverts, and some large culverts have been called bridges. If the traffic is borne directly on the top or roof of the conduit, it must be designed as a bridge, and may be called a bridge, no matter what its length or height. If a considerable thickness of the roadbed passes over the conduit so that water may stand above it at one end and pass through under pressure, the structure may properly be called a culvert.

18. The **area of waterway** required can not be determined by any rule. It depends upon the maximum rate of rainfall, the kind of soil, whether rocky, sandy, clayey, etc., and the slope of the surface and its condition, whether cultivated or not, timbered or not, frozen or not, etc.

If the culvert conveys the flow of a side ditch under the road, its capacity should be equal to that of the ditch. The discharging capacities of channels of different forms are to each other as the squares of their areas divided by their surface widths; thus, the area of the side ditch in figure 3 is 3½ square feet. The area squared = 12.25. The surface width is 2½ feet; hence the area squared divided by the width = 12.25 ÷ 2½ = 4.9. To find the dimensions of a rectangular conduit of equal capacity, assume the width 1½ feet. Then the area squared divided by 1½ = 4.9; hence, the area squared = 7.3, or the area = 2.7; the depth equals the area divided by the width = 2.7 ÷ 1.5 = 1.8; hence a conduit of equivalent section will be 1.5 by 1.8 feet.

Required, the size of a circular conduit equivalent to the side ditch. Divide the equivalent number 4.9 by 0.616, and take the cube root of the quotient, which will be the diameter of the circle; thus, 4.9 ÷ 0.616 = 8; the cube root of 8 = 2, which is the diameter of the equivalent circular conduit.

intrados, nor any of more than three-fourths inch of mortar alone. Greater spaces between stones should be filled with shims or spalls coated with mortor and well driven in. All joints should be completely filled with mortar.

If brick are used, they are laid as indicated in figure 18. The concentric circles are called rings, and the thickness of brick arches is sometimes given as 3, 4, etc., rings. Under the rule given above, a brick arch will have at least three rings. Particular attention should be paid to the surfaces between rings, which must be separated by a film of mortar in good contact with both surfaces and monolithic, so far as possible, with the mortar in the radial joints.

Spandrel filling.—The stability of the arch requires that it be permanently loaded on its haunches. This may be done by depositing any heavy material, but in small arches is commonly done by continuing the masonry from the outside of the arch ring to a line or curve swept from the crown to the outer edge of the top of the abutment. For culverts, the embankment supplies the necessary weight, and the main function of the spandrel filling is to give a smooth and regular slope to the top of the structure to promote the run-off of water.

Spandrel walls.—At each end of the arch a wall is built up to the level of the crown and in length from out to out of the abutments. It acts to stiffen the arch and also as a retaining wall for the embankment over it. For wide or very long arches there may be interior spandrel walls of similar dimensions, and in small arches the masonry may be built up to these lines all along.

Wing walls.—These are built from the ends of the spandrel walls with a splay of about 30°, and act as buttresses for the spandrel walls and also as retaining walls for part of the embankment left unsupported by the cut made to give access to the culvert. The tops of the wing walls are not horizontal, but slope with the earth of the embankment.

The thickness of wing walls may be slightly less than that of retaining walls. The bond with the spandrel wall gives support to the highest part, and the slope of the embankment affords relief against great pressure. For brick or fair rubble in cement mortar the thickness should be one-sixth of the height throughout, or one-twelfth at the top and one-third at the bottom, the top, however, to be not less than 18 inches for rubble and 13 inches for brick. As the height varies the thickness does also. Determine the thickness at the spandrel wall and at the toe of the embankment and vary it uniformly from one to the other. The coping may be inclined (fig. 19) or in steps (fig. 20). In the former case the stones must be well anchored to the wall to prevent sliding. The step form is much better. For a high wall the coping will be of uniform width and will form a low parapet on the front edge of the top surface (fig. 7). Except as above noted, all the requirements of retaining walls apply to wing walls.

Concrete arches, on account of their great homogeneity and the ability of the material to take tensile as well as compressive strains may be of reduced dimensions, and the spandrel filling is most conveniently combined with the arch ring in a monolith. For thickness of crown add 25 to the span in feet and divide by 5. The result will be the thickness at the crown in inches. The extrados is a cylinder passing through the crown and the outer top edges of the side walls. Its radius will be about equal to the span and may be so taken. Side, spandrel, and wing walls of concrete culverts have the same proportions as for other masonry.

21. **Centers.**—All arches must be supported during construction and until the mortar has set sufficiently to bear the pressure. Supports are commonly built of wood and are called **centers. Great rigidity is necessary,** and all principal pieces must be so proportioned that they will take their stresses without appreciable deflection. Long pieces must have a radial direction so as to be in com-

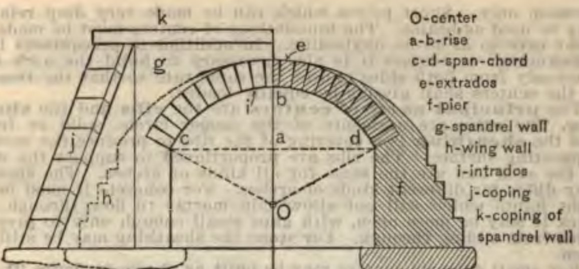


Fig. 17

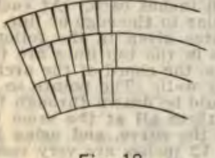


Fig. 18

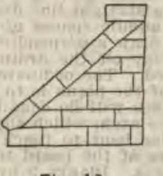


Fig. 19

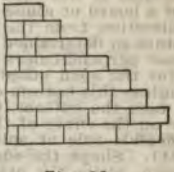


Fig. 20

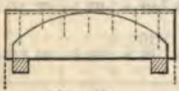


Fig. 21

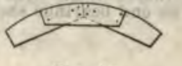


Fig. 23

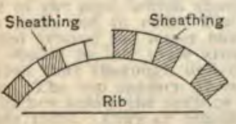


Fig. 22

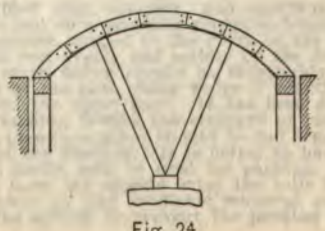


Fig. 24

pression only. Short pieces which can be made very deep relatively may be used as beams. The foundations of centers must be made with great care so as to be unyielding. In addition to precautions in the construction of centers it is also necessary to build the arch simultaneously from both sides and at the same rate so that the two sides of the centers shall always be equally loaded.

The **principal parts** of **centers** are the **ribs** and the **sheathing.** The **ribs** are segments of the proper circle, solid or framed, and the **sheathing** is a covering of the ribs to produce the necessary supporting surface. The ribs are proportioned to support the weight of the arch and are the same for all kinds of arches. The sheathing may differ for different kinds of arches. For concrete it must be with tight joints which will not allow thin mortar to flow through. For brick it may be more open, with gaps small enough only to prevent a brick from sliding through. For stone the sheathing may be still more open.

For small culverts centers may be built as shown in figure 21. For larger arches figure 24 shows a convenient construction. The radial supports will vary in number according to the size of the arch. The points supported on the ribs need not be less than 3 or 4 feet apart. The distances between ribs will be 2 to 3 feet, depending on the thickness of the sheathing.

22. **Laying out centers.**—For small arches lay down the material of the ribs and strike the curves of the centers with a radius. When this method is not convenient make a template or pattern. On the edge of a board or along a straight line drawn near the edge lay off in each direction from the middle spaces of 6 inches each. At each of the points so determined draw a perpendicular to the edge or line, and on these perpendiculars lay off the ordinates given in the following table for the span adopted. The ordinates in the top lines are to be used unless this bottom of the plank is to be the chord of the arch, in which case the bottom lines will do equally well. The points so laid off are on the curve of the arch, which should be drawn through them by a flexible rule or spline bent to touch them all at the same time (fig. 21). Shape the edge of the board to the curve, and using it as a pattern, scribe the others. Planks 2 by 12 inches are very convenient material for ribs. From the table it will be seen that such a plank will cut the whole rib for a 3-foot arch, and by adding a 3-inch strip on the top edge it will give a rib for a 4-foot arch. For larger arches build up the ribs by putting segments end to end with a close bearing and fasten them with other segments put on as fish plates (fig. 23.) The end bearings should not be less than 3 inches.

TABLE I.

23 **Middle and side ordinates for segmental arches** with rises =¼ span. Ordinates in top lines measured from the tangent; ordinates in bottom lines measured from the chord.

Span.	Radius.	Rise or middle ordinates.	Ordinates in feet at distances from middle of—									
			0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
3	1.87	0.75	0.06 .69	0.36 .39	0.75 .00							
4	2.50	1.00	.05 .95	.21 .79	.50 .50	1.00 .00						
5	3.12	1.25	.04 1.21	.17 1.08	.42 .83	.78 .47	1.25 .00					
6	3.75	1.50	.03 1.47	.14 1.36	.31 1.19	.49 1.01	.95 .55	1.50 .00				
8	5.00	2.00	.03 1.97	.10 1.90	.23 1.77	.42 1.58	.67 1.33	1.00 1.00	1.50 .50	2.00 .00		
10	6.25	2.50	.02 2.48	.08 2.42	.18 2.32	.33 2.17	.52 1.98	.77 1.73	1.18 1.32	1.45 1.05	2.15 .35	2.50 .00
12	7.50	3.00	.02 2.98	.07 2.93	.15 2.85	.27 2.73	.43 2.57	.62 2.38	.87 2.13	1.16 1.84	1.50 1.50	1.91 1.09
14	8.75	3.50	.01 3.49	.07 3.43	.13 3.37	.23 3.27	.36 3.14	.53 2.97	.73 2.77	.97 2.53	1.37 2.13	1.57 1.93
16	10.00	4.00	.01 3.99	.05 3.95	.11 3.89	.20 3.80	.32 3.68	.46 3.54	.63 3.37	.83 3.17	1.07 2.93	1.34 2.66
18	11.25	4.50	.01 4.49	.05 4.45	.10 4.40	.19 4.31	.28 4.22	.42 4.08	.55 3.95	.75 3.75	.95 3.55	1.15 3.35
20	12.50	5.00	.01 4.99	.04 4.96	.09 4.91	.16 4.84	.25 4.75	.36 4.64	.50 4.50	.67 4.33	.84 4.16	1.05 3.95

24. **Pipe culverts.**—Vitrified clay, concrete, and cast-iron pipe culverts should, if possible, be laid on a carefully prepared foundation of broken stone, gravel, or concrete, shaped to the curve of the lower part of the pipe, which should rest evenly and solidly on the foundation from end to end. The earth filling should be thoroughly compacted around the lower part of the pipe, using water if practicable, but should be left loose around the upper part. It has been demonstrated that thorough undertamping trebles the strength of concrete pipe. The top surface of earthenware pipes should be not less than 18 inches below the surface of the roadbed. It is better to have the joints tight. Clay or cement motar may be used for packing. Care should be taken in laying to have the spigots enter the bells to the full length. Oakum, rope, grass, or any available material may be put in first and rammed to the bottom to prevent the packing mate-

rial from running through into the pipe. Pipe culverts should run dry when the flow ceases. They should have an average fall of not less than 1 in 72 for vitrified and 1 in 225 for cast-iron pipe. The fall should not be uniform, but should increase slightly from the upper to the lower side, giving the pipe a camber which will prevent the formation of pockets by settlement.

The ends of pipe culverts should be protected by head walls. These may be of rubble or brick masonry, or for temporary purposes of wood (figs. 25 and 26).

Vitrified pipe is made in 2 and 3 foot lengths; the former is the standard market length. Up to 2 feet in diameter it usually comes in bell-and-spigot form. Larger sizes are ordinarily in cylindrical form with rings of the same material to cover the joints. The trade designation of vitrified and cast-iron pipe is the **inside diameter.**

Cast-iron pipe is made in 12-foot lengths, and is bell and spigot for all sizes.

Concrete pipe, if used, will be made on the site. The thickness should be 1 inch for all up to 12 inches diameter. Above 12 inches, a thickness of one-twelfth the diameter.

25. **Surfacing.**—It is of great importance to keep the surface of earth roads smooth and free from ruts as far as possible. During continuous rainy weather it is usually not practicable to do this, but as soon as the road has dried out enough to permit it, the surface should be gone over and the ruts and other depressions filled up. If this is done, the mud from the next rain will be very much less, and by attention to this simple expedient a road that would be constantly bad with intermittent rains can be kept good most of the time. An excellent opportunity for such work arises when a badly cut road is lightly frozen, and especially just as the frost is beginning to come out of the ground.

The work may be done by men with picks and shovels, or by the use of harrows and scrapers drawn by animals. A good farm harrow gives excellent results. A scraper may be improvised by putting a tongue on a piece of heavy plank, and a steel shoe on its lower edge (fig. 27). A railroad rail is said to make an excellent scraper. A team is hitched to each end. For soft mud a drag which will do much good is made by splitting a 12-inch log in halves, placing them round sides down on the ground 2½ feet apart, and nailing cleats across their flat sides. (See par. 25*a*, p. —.)

The **scraping grader** is a scraper mounted on wheels and adjustable as to height. It hangs obliquely over the road, the outer end in advance, so that the surplus earth is pushed toward the center. With such a machine on hand, the manner of using it will be obvious. One may be improvised by hanging the heavy plank and steel shoe shown in figure 27 under the bed of an ordinary wagon.

26. The **quality of the earth** has a great influence upon its behavior in a road. Clay compacts well but will not drain. Sand drains well but usually will not pack. There are some exceptions to this rule, notably among the volcanic sands of the Philippine Islands, which are sharply angular in grain and do pack well enough to make a fairly good road metal. It is also to be observed that sand packs under pressure when damp, and that sandy roads are usually better in wet than in dry weather, for which reason nothing is done to promote drainage of very sandy roads. A road which is too sandy may be improved by an admixture of clay, and conversely. Gravel, with a certain proportion of clay, makes an excellent road. The combination is similar to that which produces the hardpan, sometimes found in excavations.

27. A **road good in all conditions of weather** can be obtained only by the introduction of materials other than earth. These materials must be of such character that they will offer a bearing surface not affected by moisture, and of such thickness as will distribute the load so that the soil below can bear it without compression. It is also requisite that the surface be smooth enough for easy

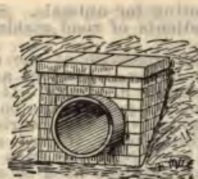


Fig. 25

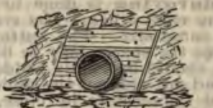


Fig. 26

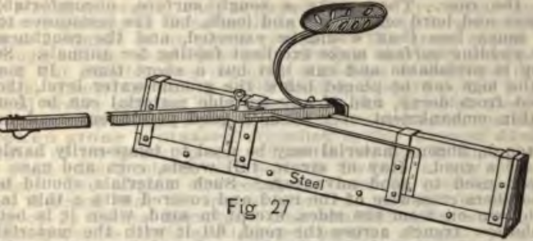


Fig 27

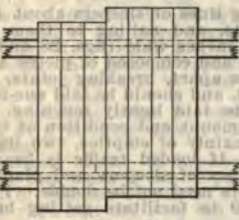


Fig. 28

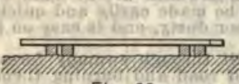


Fig. 29

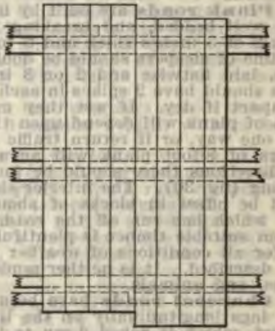


Fig. 30

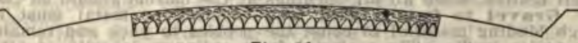


Fig. 31

traction and rough enough to give a footing for animals. Such constructions range from the simplest expedients of road making to the highest class of street pavements.

Corduroying is done by laying logs crosswise of the road and touching each other. The result will be better if the logs are nearly of the same size. The butts and tips should alternate. If the logs are large the spaces may be filled with smaller poles. The bottom tier of logs should be evenly bedded and should have a firm bearing at the ends and not ride on the middle. The filling poles, if used, should be cut and trimmed to lie close, packing them about the ends if necessary. If the soil is only moderately soft the logs need be no longer than the width of the road. In soft marsh it may be necessary to make them longer.

The logs may be utilized as the wearing surface. In fact this is usually the case. They make a rough surface, uncomfortable for passengers and hard on wagons and loads, but the resistance to traction is much less than would be expected, and the roughness and slightly yielding surface make excellent footing for animals. Surface corduroy is perishable and can last but a short time. In marshes, where the logs can be placed below the ground-water level, they are preserved from decay, and if any suitable material can be found to put a thin embankment over them a good permanent road may be made.

Any tough, fibrous material may be used to temporarily harden the surface of a road. Hay or straw, tall weeds, corn and cane stalks have been used to good advantage. Such materials should be laid with the fibers crosswise of the road and covered with a thin layer of earth thrown on from the sides, except in sand, when it is better to dig a shallow trench across the road, fill it with the material, and then dig another trench just in front of and in contact with the first, and throw the sand from it back onto the material in the first trench, etc.

28. **Plank roads** are built by laying lines of sleepers about 4 feet apart, well bedded, and breaking joints, and nailing to them cross planks 2 or 3 inches thick and 9 to 12 inches wide (figs. 28 and 29). Each line of sleepers should be doubled and composed of pieces 4 by 6 inches, laid flatwise and 2 or 3 inches apart, breaking joints. The planks should have 2 spikes in each end, and should be laid one-fourth inch apart if dry. If wet they may be laid lightly touching. The length of plank will depend upon the amount and condition of traffic. If all one way, or if return traffic is mainly of empties, two lines of sleepers of 8-foot plank will answer. If loaded traffic is heavy in both directions there should be four lines of sleepers and planks 14 feet long (fig. 30). The interior sleepers need not be double. Planks should be offset in blocks of about 20 to facilitate getting back a wheel which has run off the road.

When suitable timber is plentiful and sawmills are at hand a good road for all conditions of weather can be made easily and quickly as above described. It is neither muddy nor dusty, and is easy on loads, wagons, and animals.

29. **Charcoal roads** have been built through swampy forests by piling logs longitudinally on the line of road and burning them into charcoal, which is raked down to 2 feet thickness in the middle and 1 foot at the edges. The logs may be 12 to 24 feet long, in piles 5 or 6 feet high, 9 feet wide at the bottom, and 2 feet wide at the top. The piles are covered with straw and earth and burned with a restricted air supply. Good draft should be permitted until the pile is well ignited, when all air openings at the bottom should be closed.

30. **Gravel** to form a good road covering or metal must have enough binding material to cause the pebbles to pack and remain in place under traffic. The material from ordinary deposits or pits of [illegible] will usually make a fair road. That from beaches and streams [illegible]t, unless binding material is supplied. If there is a considerable [illegible]oportion of stones larger than 4 inches diameter they should

be broken up or excluded. For gravel and for all other metal roads the roadbed is first brought to the shape and condition described for an earth road, but at a grade lower than the proposed surface of the road by the thickness of the metal. This lower grade is called the **subgrade.** In excavated roads and those formed by crowning on the natural surface the subgrade is formed at the first operation. For roads on embankments it is better to bring the fill up to the final grade, and then, just before putting on the metal, excavate to subgrade, forming a **trough** or **box** in which to deposit the metal.

The first or bottom course of gravel should be about 4 inches thick, and should be well compacted by travel or by rolling before the next layer is deposited. The following courses should be of the same thickness, each compacted as laid. The net thickness of three such layers will be about 10 inches and will make a good road of the class.

31. **Broken stone** and **crushed stone** are terms applied to angular fragments of stone made by breaking up larger pieces either by hand hammers or by power crushers. The stone should be hard and tough and not very absorbent. Trap is the best; granite is good at first, but disintegrates rapidly; sandstone is deficient in binding qualities. Limestone has excellent binding properties, but is generally soft and wears rapidly; it is, however, the material most used in stone roads because more plentiful than stone of better quality.

Broken stone is **classed** according to the **largest dimension** in inches of its largest pieces. The test of size is that the largest piece shall pass freely in any position through a ring of a certain diameter. The largest size commonly used in road making is 2½ inches, meaning that the largest piece can not fail to pass through a ring of 2½ inches diameter. The smallest usual size is ½ inch. Sometimes double limits are imposed, as that all shall pass through a 2½-inch ring and none through a 1½-inch ring. The **run of the crusher** means all material which comes from the crusher not exceeding the specified size. Stone broken by hand can not be graded in sizes. It is considered by some than hand-broken stone is superior on account of the more nearly cubical shape of the fragments and the less quantity of small pieces. The advantage if any is not enough to outweigh the greater rapidity and economy of machine breaking. Hand breaking will be used only when there are no crushers and plenty of labor.

For breaking stone by hand the best hammers are of steel in the form of a circular disk, of 2 to 3 pounds weight, with rather long handles.

Broken stone is measured by the ton or by the cubic yard; by the ton, when it can be passed over scales or measured by displacement of vessels; otherwise by the yard. For a rude comparison, the cubic yard and the long ton may be taken as equivalent.

32. **Macadam roads** are made of broken stone deposited on the natural surface, or preferably on a properly prepared subgrade and compacted by traffic or by rolling. For military roads compacting by traffic will be the rule and by rolling the exception. Better results will be obtained if the stone is put on in two layers, the lower one compacted before the upper one is spread. If graded stone is to be had, use 2½ inch for the lower course and 1½ to 2 inch for the upper. When compacted by traffic, the thickness of the lower course when first spread must be enough to prevent the wheels cutting through it. If the foundation is dry and hard, 4 inches will be right; if the foundation is yielding, a greater thickness will be necessary, and it may happen that all will have to be put on at once to carry the traffic while compacting. On a 4-inch bottom layer, a 3-inch top course may be spread.

The **width** to be **stoned** or **metaled** will depend upon the conditions of the moment. Ten feet will do for a single line of wagons, or 16 feet for a double line. If the traffic in one direction is light, the width may be increased with the same amount of stone by limiting the bottom layer to the middle and extending the top layer out on the sides. Such extensions are called **wings.** This disposition requires that the earth of the roadbed shall be of excellent quality.

If the traffic can be distributed over the entire surface of the stone it will be much better. If the wagons track and quickly wear down two ruts they should be filled up by raking in stones from the sides.

33. If time, materials, and appliances are available, a **high-class macadam road** may be built as follows: Prepare the subgrade and compact it thoroughly by rolling. Lay a bottom course 6 inches thick of 2¼ to 2½ inch stone, and roll it down to 5 inches or less, leaving it smooth, even, and true to grade.

Lay a top course 4 inches thick of ¾ to 1½ inch stone and roll it down to 3 inches, and leave the surface as before.

Spread a layer of screenings from the same stone just thick enough to cover the projections of the top course, water and roll until to grade and so compact that no material can be picked up.

34. **Telford roads** are made by covering the subgrade with a layer of medium-size stones laid by hand, larger face down and in close contact, and filling the interstices with chips snugly set with a small hammer. On this foundation a layer of broken stone is laid and compacted as described for macadam (fig. 31). Well-made telford will probably stand on ground too soft and wet to carry macadam of reasonable thickness. It may also be preferred if the large stones are easily obtained and hand breaking is necessary.

In all work with broken stone, the compacting is more rapid and effective when the stone is wet. When roads are compacted with rollers it is worth while to arrange for a thorough sprinkling just in advance of the machine.

In using a roller it is best to roll the sides first so that the compacted sides may offer lateral resistance to prevent the material in the center spreading out when the roller passes over it. For efficient service the roller should be not less than 4 feet diameter nor weigh less than 1 ton to the foot of length.

35. Other kinds of pavement, wood or stone block, brick, and asphalt are constructed on the same principles, but require special materials, machinery and appliances, skilled labor, and expert superintendence.

36. **Noninterruption of traffic.**—The methods, and to a certain extent the plans, will be affected by the necessity of keeping the road open for use during the work of repair or reconstruction. Generally, the system will be adopted of doing one side at a time. Sometimes a new road may be built alongside the old one, or a temporary road may be opened for use while the old one is repairing. The result in any case will be to discourage changes of grade and to cause cuts and embankments to be made in horizontal layers along the whole length and not to the full height or depth at once, as would otherwise be done; to cause side cuttings in wet weather to be all cut and no fill and to encourage preparation and distribution of materials along the road, ready to be put on quickly.

37. **Location.**—Much military road work, especially of repairs, will be done under conditions which will make instrumental location impossible. When it can be done, it will be advantageous to mark the center line with stakes at intervals of 100 feet, or less if the ground is irregular, and to mark the grade on each stake. If levels are not run, the grade can be marked by the eye. From the center stakes side stakes may be set to mark the outer edges of the side ditches. Lines stretched on the center and side stakes will be of assistance in getting the true lines and grades quickly. If the side lines are stretched parallel to the grade, they will be at a uniform distance above the bottom of the side ditches and can be used as guides in finishing the latter.

In the **location of a new road** more instrumental work is desirable. The general line will be laid down on a map. This line will be run out on the ground, correcting obvious difficulties, marked by es 50 or 100 feet apart, and the height of ground at each stake rmined. The slope of the ground at right angles to the line will be noted at every stake, as also the distance of any obstacles on either side which would make it difficult to shift the line. The character of the soil will be carefully noted.

From these notes a **profile of the ground** will be made with suitable horizontal and vertical scales (see Reconnaissance). On this ground profile a profile of the road will be laid down. This profile will follow the natural surface so long as no heavy grades result. When the grades are too steep the notes will be consulted to see if grades can be reduced by shifting the line to one side. If this can not be done, the road profile will be so drawn as to make the cuts and fills equal in volume. The locations of bridges and culverts will be noted on the profile, as also the lengths requiring especial treatment, as corduroying, etc.

Having fixed the lines and grades, determine the cuts or fills at the stakes and the lateral deviations of the lines, if any are decided upon, and go over the ground again, staking out the changes in the line and marking on each stake the cut or fill in feet below or above its top. The usual method is to write **cut** or **fill,** or **C** for cut and **F** for fill, with the figures indicating its amount immediately below.

38. **Side stakes** are those used to mark the intersections of the side slopes of cuts or embankments with the natural ground surface. They are set on each side of the center stakes on lines at right angles with the traverse. Their distances from the center stake, called **side distances, d_r** and **d_l** (fig. 32), depend on the depth of cut or height of fill, width of bottom or top, slope of sides, and the transverse gradient of ground surface.

The **vertical distances** from the ground surface at the side stakes to the level of top of embankment or bottom of cut are called **side heights, h_r** and **h_l** (fig. 32).

If the ground is level, the side distances are the same and are equal to $\frac{1}{2}w + cs$, in which w=the width of top of embankment or bottom of cut; c=the center cut or fill, and s=the number of units horizontal to 1 unit vertical in the side slopes.

If the ground slopes from the center to the side stakes, the determination of side distances and heights can not be directly made by any formula simple enough to be of practical use. The relation is $d_r = \frac{1}{2}w + h_r s$, which is not determinate, because d_r and h_r are not independent of each other. The method of trial and error must be used by applying the following rule: Estimate the side height and work out the side distance by the formula $d_r = \frac{1}{2}w + h_r s$, or $d_l = \frac{1}{2}w + d_l s$. Measure off the resulting distance to right or left of the center stake and take the ground level at the point found. If it is the same as the estimated level, it is correct and the stake may be driven. If the **measured** elevation is **greater** than the **estimated,** multiply the difference by the slope ratio and add the product to the trial side distance. If the **measured** elevation is **less** than the **estimated,** multiply as before and subtract the product from the trial side distance. Lay off the new distance for the second trial side distance and repeat the operation. A little practice will enable a sufficiently correct result to be got at the first trial. Side staking will not often be necessary for military roads.

39. In **metaling** a road much more attention to lines and grades is necessary. After the grading is finished, center and side stakes should be set and marked with grade and subgrade instrumentally determined.

40. **Curvature.**—Horizontal curves for changes of direction can be put in by the eye with sufficient accuracy. Run out the two tangents to points beyond where the curve will leave them. Select on each a point where the curve is to begin and set stakes at these points. Lay a line loosely between the stakes and with small pickets 5 feet apart throw the line into a curve and shift the pickets until the curve is fair and on the desired ground, letting out or taking up the length of the line accordingly as it proves to be too short or too long. If the curve can be made level, it is better to do it;

if not, the roadway must be widened to permit long teams to straighten out and pull (fig. 33). This is important for mountain roads, which combine steep grades and short turns. If the width of the road **outside of the center line** is made equal to 1,600 divided by the **radius of curvature** in feet, it will be wide enough for an 8-mule team. If the radius of curvature exceeds 200 feet no widening is required.

To find the radius of a curve which has been staked out, stretch a string from any stake to the third, fifth, or seventh stake in either direction and measure the distance from the string to the stake opposite its middle point. This distance is called a **middle ordinate.** The **radius of curvature** in feet is the length of the string in feet squared, divided by eight times the middle ordinate in feet. The stakes must be equidistant.

41. **Intersections of rising grades** should be flattened so that the rise on either side shall not exceed 2 feet in the last 100 feet. All abrupt changes of grade should be softened. This can be done well enough by the eye. If not done in construction it will soon be done by the weather and traffic.

42. **Estimates for earthwork.**—The calculation of quantities in excavations and embankments will usually be for balancing cuts and fills, and for making requisitions for men, teams, and tools. For these purposes a simple rapid method giving approximate results is best.

Volumes are derived from the **areas of cross sections** of the cut or embankment and the **distances** between them. The distances can be directly measured, and to any desired accuracy. The uncertainty in the volume resides entirely in the determination of the cross-sectional areas. The cross section to be multiplied by any distance to deduce a volume is assumed to be the average cross section for that distance. The more uniform the ground the easier will be the measurement of any section and the fewer sections will be necessary in a given distance to get a fair average. Experience has shown that for **ordinary ground** the **average** section for 100 feet in length is very nearly one-half the sum of the **actual** sections at the ends of the same 100 feet. The difference is so small that it may be neglected when the end areas do not differ widely in size and the ground between changes regularly from one to the other.

43. When the ground has no transverse slope the sections are called **level sections.** For these the area depends upon the center cut or fill, the bottom or top width, and the slope of the sides. Volumes per 100 feet of line for level sections, with center cuts or fills of 1 to 24 feet, and widths of 16, 18, 20, 22, and 24 feet, and side slopes of 1 to 1, 1½ to 1, and 2 to 1 are given in Table II. To use this table it is only necessary to know the center cut or fill, the width, and the side slopes, and of these only the first requires a measurement on the ground. For preliminary estimates, the average cut or fill for the entire length of a cutting or embankment may be used, and the resulting volume per 100 feet taken from the table may be multiplied by the number of hundreds of feet in the entire distance for the total volume.

TABLE II.

44. **Volumes** in cubic yards of sections 100 feet long of cuts or embankments on level ground with side slopes of 1 to 1:

Center cut or fill in feet.	Width of base of cut or crown of fill in feet.					
	14	16	18	20	22	24
1	56	63	70	78	85	92
2	119	133	148	163	178	192
3	189	211	233	256	278	300
4	267	296	326	356	385	415
5	352	389	426	463	500	537
6	444	489	533	578	622	667
7	544	596	648	700	752	803
8	652	711	770	830	889	948
9	767	833	900	967	1,033	1,100
10	889	936	1,037	1,111	1,185	1,259
11	1,019	1,100	1,181	1,263	1,344	1,426
12	1,156	1,244	1,333	1,422	1,511	1,600
13	1,300	1,396	1,493	1,589	1,685	1,781
14	1,452	1,556	1,659	1,763	1,867	1,970
15	1,611	1,722	1,833	1,944	2,055	2,166
16	1,778	1,896	2,015	2,133	2,251	2,370
17	1.952	2,078	2,204	2,330	2,456	2,581
18	2,133	2,267	2,400	2,533	2,666	2,800
19	2,322	2,463	2,604	2,744	2,885	3,025
20	2,519	2,667	2,815	2,963	3,111	3,259
21	2,722	2,878	3,033	3,189	3,344	3,500
22	2,933	3,096	3,259	3,422	3,585	3,748
23	3,152	3,322	3,493	3,663	3,833	4,003
24	3,378	3,556	3,733	3,911	4,089	4,266
25	3,611	3,796	3,981	4,167	4,352	4,537

If the material is friable, the halves of the log may be placed on edge, flat sides forward and 2 or 3 feet apart, connected by cross-pieces.

Volumes in cubic yards of sections 100 feet long of cuts or embankments on level ground with side slopes of 1½ to 1:

Center cut or fill in feet.	Width of base of cut or crown of fill in feet.					
	14	16	18	20	22	24
1	57	65	72	80	87	94
2	126	141	156	170	185	200
3	206	228	250	272	294	316
4	296	326	356	385	415	444
5	398	435	472	509	546	583
6	511	556	600	644	688	733
7	635	687	739	791	843	894
8	770	830	889	948	1,007	1,066
9	917	983	1,050	1,116	1,183	1,249
10	1,074	1,148	1,222	1,296	1,370	1,444
11	1,243	1,324	1,406	1,487	1,568	1,650
12	1,422	1,511	1,600	1,689	1,778	1,866
13	1,613	1,709	1,806	1,902	1,998	2,094
14	1,815	1,919	2,022	2,126	2,230	2,334
15	2,028	2,139	2,250	2,361	2,472	2,583
16	2,252	2,370	2,489	2,607	2,725	2,844
17	2,487	2,613	2,739	2,865	2,991	3,117
18	2,733	2,867	3,000	3,133	3,266	3,400
19	2,991	3,131	3,272	3,413	3,554	3,694
20	3,259	3,407	3,556	3,704	3,852	4,000
21	3,539	3,694	3,850	4,005	4,161	4,316
22	3,830	3,993	4,156	4,318	4,481	4,644
23	4,131	4,302	4,472	4,642	4,812	4,983
24	4,444	4,622	4,800	4,978	5,156	5,333
25	4,769	4,954	5,139	5,324	5,509	5,694

TABLE II—Continued.

Volumes in cubic yards of sections 100 feet long of cuts or embankments on level ground with side slopes of 2 to 1:

Center cut or fill in feet.	Width of base of cut or crown of fill in feet.					
	14	16	18	20	22	24
1	59	67	74	81	88	96
2	133	148	163	178	193	207
3	222	244	267	289	311	333
4	326	356	385	415	444	474
5	444	481	519	556	593	630
6	578	622	667	711	755	800
7	726	778	830	881	933	985
8	889	948	1,007	1,067	1,126	1,185
9	1,067	1,133	1,200	1,267	1,333	1,400
10	1,259	1,333	1,407	1,481	1,555	1,629
11	1,467	1.548	1,630	1,711	1,792	1,874
12	1,689	1,778	1,867	1.956	2,045	2,133
13	1,926	2,022	2,119	2,215	2,311	2,407
14	2,178	2,281	2,385	2,489	2,593	2,696
15	2,444	2,556	2,667	2,778	2,889	3,000
16	2,726	2,844	2,963	3,081	3,200	3,318
17	3,022	3,148	3,274	3,400	3,526	3,652
18	3.333	3,467	3,600	3,733	3,866	4,000
19	3.659	3,800	3,941	4,081	4,222	4,362
20	4,000	4,148	4,296	4,444	4,592	4,740
21	4,356	4,511	4,667	4,822	4,977	5,133
22	4,730	4,889	5,052	5,215	5,378	5,541
23	5,111	5.281	4,452	5,622	5,792	5,963
24	5,511	5,689	5,867	6,044	6,222	6,400
25	5,926	6,111	6,296	6,481	6,666	6,851

45. For **ground which has a lateral slope** another variable must be introduced, for with a given depth, width, and side slopes the area will not be the same for different ground slopes. For every such section there is a level section of the same area, and having the same bottom width and side slopes. This is called the **equivalent level section.** If the ratios between the depths of oblique sections and their equivalent level sections are known, the areas of the oblique sections can be taken from the foregoing table.

The **ratios** between **center cuts** or **fills** of oblique sections and the **center cuts** or **fills** of the equivalent level sections are given in the following table in percentages, by which the **actual center cut** or **fill** of the oblique section must be **increased** to produce the **center cut** or **fill** of the **equivalent level** section. The table gives values for transverse gradients of 15 to 1 to 5 to 1, and for side slopes of 1 to 1, 1½ to 1, and 2 to 1.

To use the table, take from the line corresponding to the gradient and the column corresponding to the side slope, the percentage factor, and increase the center cut or fill by this percentage. The result will be the depth of the equivalent level section. With this increased depth enter the table of level sections and take out the volume for a length of 100 feet. This method will give results correct to ½ per cent, corresponding to an accuracy in the levels of $\frac{1}{10}$ foot in 20 feet.

TABLE III.

46. **Percentages to be added to center heights** of sidehill embankments and cuttings to obtain the center height of the level section of equal area:

Transverse gradient of ground surface.	Side slopes of cut or embankment.		
	1 to 1.	$1\frac{1}{2}$ to 1.	2 to 1.
15 to 1	0.02	0.03	0.04
14 to 1	.03	.03	.04
13 to 1	.03	.04	.05
12 to 1	.03	.04	.06
11 to 1	.04	.05	.08
10 to 1	.05	.07	.09
9 to 1	.06	.08	.12
8 to 1	.07	.11	.14
7 to 1	.09	.14	.19
6 to 1	.13	.19	.27
5 to 1	.18	.27	.41

47. To **balance** the **cut** and **fill** in a **side cutting** the center line should be run so that there will be a slight cut along it. This will give a small excess of volume of cut over volume of fill, which is desirable.

48. **Handling earth.**—The excavation of a mass of earth and its formation into an embankment may be classified into **loosening, loading, hauling,** and **spreading.**

Loosening with a plow will require 2 horses, 2 men, and a plow for each 40 yards per hour. If very hard, 4 horses will be required for the plow. With picks, 1 man for each 40 yards per day, or 10 men equal 1 plow.

Loading material into carts or wagons will require 1 man for each 2 yards per hour. All other loading is included as a part of the hauling.

The **haul** or **lead** is the distance to be traveled from the point of loading to the point of dumping. The **mean haul** is the quantity usually considered, and is the distance from the center of gravity of the cut or excavation to the center of gravity of the fill.

The following table gives the yardage made on various leads for wagons, carts, wheel and drag scrapers, wheelbarrows, and boxes, or other improvised facilities. The load units assumed are 1 yard for wagons, $\frac{1}{2}$ yard for carts and wheel scrapers, $\frac{1}{4}$ yard for drag scrapers, $\frac{1}{14}$ yard for wheelbarrows, and $\frac{1}{10}$ yard as a load for 2 men, carried in a box or otherwise.

Table IV.

49. **Yardage of earth** which can be handled **per hour** in different conveyances:

Length of haul in feet.	Yardage per hour per conveyance for hauling in—				
	Wagons.	Carts or wheel scrapers.	Drag scrapers.	Wheel-barrows.	In tubs or boxes.
40 or less			22.0	2.5	2.0
50			14.0	2.2	1.8
75			10.0	1.9	1.6
100	12.0	6.0	8.0	1.7	1.4
200	10.0	5.0	4.2	1.2	.9
300	8.6	4.3		.9	
400	7.5	3.7		.7	
500	6.7	3.3		.6	
600	6.0	3.0			
700	5.5	2.7			
800	5.0	2.5			
900	4.6	2.3			
1,000	4.3	2.1			

A wagon should be loaded in 4 minutes or less and a cart in 2 minutes or less. There should be at least 6 shovelers for each wagon at each loading point, and at least 3 for each cart. One gang of shovelers should not be required to load more than 10 wagons or carts per hour.

Wagons for hauling earth should have the ordinary box replaced by a bed formed of side boards, front and tail gates, and a bottom of scantling about 3 by 4 inches, not fastened together. The side boards should have cleats on the outside to take the standards of the bolsters, and other cleats on the inside to receive the head and tail gates. The pieces of the bottom should have cleats on the underside to take the rear bolster. To dump a load from such a wagon the ends are first removed, then one side board is raised and dropped down on the hubs outside the bolster. Beginning on this side, the bottom pieces are pulled up one at a time, allowing the dirt to sift through. For dumping wagons there should be 2 men at each dumping point, and, if provided with shovels, they should be able to take care of the spreading.

Carts and **scrapers** are dumped by the driver and deposit the entire contents in one pile. For this kind of hauling, spreaders should be provided at the rate of 1 man for each 10 yards per hour.

Example.—Having a cut to make 400 feet long with an average center depth of 10 feet and a bottom width of 18 feet, side slopes of 2 to 1, and a transverse ground slope of 10 to 1; the material to be placed in an embankment 600 feet long adjacent to one end of the cut; the work to be done in 24 hours; material to be handled, a light loam. What requisitions should be made?

From Table III take the coefficient corresponding to 2 to 1 and 10 to 1 slopes, 0.09, and add this percentage to the actual depth 10 feet, giving 10.9 feet, or, say, 11 feet depth of equivalent level section. From Table II for level section of 11 feet cut, 18 feet wide, and 2 to 1 slopes, take the quantity 1,630, which is the yardage in 100 feet of the cut, giving 1,630×4=6,520 for the total yardage to be handled.

Loosening will require 2 horses, 1 plow, and 2 men for each 40 yards per hour, or 6,520÷40=163 hours for the whole, which will require 168÷24=7 plows to do the work in 24 hours. If 7 plows can not be had, substitute 10 men with picks for each plow short. If no plows are to be had, 70 men with picks will be needed.

The mean haul will be 400+600÷2=500 feet. Table IV shows this can best be done with wagons, and that each wagon will take care of 6.7 yards per hour at that distance, or 160 yards in 24 hours; hence 6,520÷160=41 wagons. A wagon and a half will haul 10 loads per hour, and hence there should be a loading gang for each wagon and a half, or 27 gangs of 6 men each equal 162 men, with shovels for loading.

Dumping and spreading will require 10 men with shovels. The total force working continuously will be:

Kind of work.	Number of men.	Number of tools.	Number of animals.
Loosening	14	7 plows	14
Or if without plows	70	70 picks	
Loading	162	162 shovels	
Hauling	41	41 wagons	82
Spreading	10	10 shovels	

Total, 227 men and 96 animals if plows are used; or 283 men and 82 animals if picks are used.

To supply this force for continuous work for 24 hours, there should be at least 1,000 men and 200 animals.

50. **Estimating rock.**—The principles are the same as for earth, but the surfaces are likely to be less regular, and greater accuracy is desirable on account of the labor of excavation. On the other hand, the side slopes, which in rock may be nearly vertical, introduce much less difficulty in computation than the flatter earth slopes. It is best to give the side slopes in rock a slight batter. Cross sections should be measured at distances of 25 feet or less. If irregular, it will be best to plot the cross sections on paper and measure the area by squares. (See Reconnaissance.)

If cuts and fills are to be made in rock, it must be remembered that the broken rock in the fill will occupy 75 per cent more volume than the same rock did in place in the cut, but the slopes of the rock fill will be flatter than the walls of the cut and the crown may be wider. It is safe to assume that the rock taken from a cut will make an embankment of the same average width and height and 50 per cent longer.

51. In handling rock much depends on its hardness and stratification. Some rock can be pried out with crowbars, but as a rule blasting and wedging will be necessary. The frequency, depth, and direction of drill holes, and the sizes of charges will depend on the nature of the rock. For all that relates to the use and handling of explosives for this purpose, see Demolitions. As a rough rule for estimating, allow ¾ pound of explosive to 1 cubic yard of solid rock.

52. **Drilling for blasting** is best done with a jumper. This is a drill of proper length to be held by a man and struck on top alternately by 2 other men with 8 to 12 pound sledges. The holder turns the drill slightly after each blow. If the hole is deep it may be started with a drill of convenient length and finished with a longer one. The form of the cutting edge or bit is shown in figures 34, 35, and 36. Drills are commonly made of hexagonal or octagonal steel. The form of the bit is the same for both. Figure 34 shows a point made on an hexagonal bar, and figure 36 the point

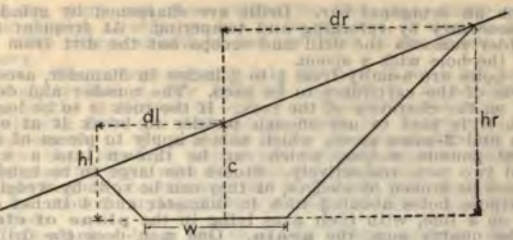


Fig. 32

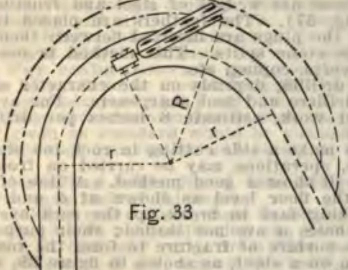


Fig. 33

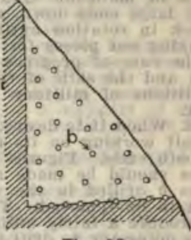


Fig. 39

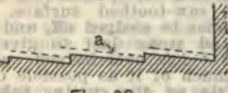


Fig. 38

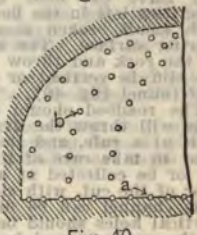
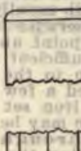


Fig. 40



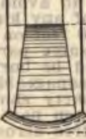


Fig. 34

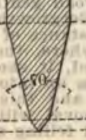


Fig. 35

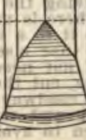


Fig. 36

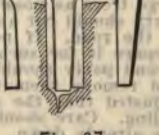


Fig. 37

made on an octagonal bar. Drills are sharpened by grinding, and when necessary by reforging and tempering. At frequent intervals the holder removes the drill and scoops out the dirt from the bottom of the hole with a spoon.

Drill holes are usually from $\frac{3}{4}$ to 2 inches in diameter, according to the form of the cartridges to be used. The number and depth will depend on the character of the rock. If the rock is to be loaded into wagons, it is best to use enough powder to break it at once into **1-man** and **2-man** stone, which names apply to pieces of about 50 and 100 pounds weight, which can be thrown into a wagon by one and two men, respectively. Stones too large to be handled may sometimes be broken by sledges, or they can be split by wedging. For this purpose holes about $\frac{3}{4}$ inch in diameter and 4 inches deep are drilled on a line, with their axes lying in the **plane of cleavage,** called by quarry men, the **grain.** One man does the drilling and striking, using a small drill the size of a cold chisel and a hand hammer of 2 to 5 pounds weight. When the holes are drilled, **plugs and feathers** are inserted. These are wedges of steel and frustums of cones of malleable iron (fig. 37). The feathers are placed in the hole, large ends down, and the plugs are inserted between them and struck in rotation until the stone splits. This method is used for breaking out pieces for culverts, coping, etc.

The rate of progress in drilling depends on the character of the rock and the skill of the drillers and tool sharpeners. For average conditions of military road work, estimate 8 inches per drill per hour.

53. When it is desired to make a side cutting in rock too steep to permit working on its face, operations may be carried on from one or both ends. Figures 38–40 show a good method. A line of drill holes should be made at the floor level as shown at *a* and other holes *b* drilled in the working face to break up the rock over the area to be removed. The holes *a* are not loaded; their purpose is to produce a fairly uniform surface of fracture to form the roadbed. It is necessary to drill them on a slant, as shown in figure 38, which will leave the floor in a saw-toothed surface. This and other asperities left in the floor must be sledged off, and the cavities filled with small broken stone and stone dust to give a proper wheel-bearing surface. The holes *b* are overcharged sufficiently to break up the rock and throw as much of it as possible over the bank. If the cliff is vertical or nearly so, the cutting takes the form of a half tunnel (fig. 40).

The roadbed should slope inward for greater security of traffic. This will throw the drainage to the wall. There will not be much of it as a rule, and there will usually be crevices in the rock sufficient to take care of it. Otherwise it must run to the ends of the cut or be collected at a low point and a channel made through the floor of the cut, with slopes sufficient to run the water over the cliff. This channel can be filled up to the road level with broken stone. Vertical holes should be drilled a few feet apart near the outer edge of the roadway and bars of iron set in them with eyes in the top through which a chain or rope may be passed to form a guard rail.

54. In **clearing a line through woods,** the work may be reduced to a minimum by curving the road gently to avoid as many large trees as possible. If there is undergrowth of any kind, a first party should cut and remove it to a distance of 20 feet on each side of the road. If needed for use elsewhere, the same party should
are it for such use. If not needed, it should be burned. The
d party should fell trees, cut them up into manageable lengths,
emove them from the roadway, and this party should be so
ed that the cutting up and removal will keep pace with the
. Care should be taken to avoid felling a tree across another
ready down.

es in the actual roadway or near its edges are best felled by
ng around them and cutting off the principal roots at 3 or 4

feet from the trunk and then pulling the tree over, stump and all. If stumps of trees already cut are to be removed, it may be done by blasting. The charge should be put low down in the stump, digging if necessary.

55. **Cost.**—The factors entering into the cost of roads are so many and so complex that a safe estimate can not be made without a knowledge of the conditions to be met in the particular case.

The following data are designed to guide the judgment in forming conclusions as to the probable limits of cost of different classes of roads, so that the first survey and estimate may be made for a road which can be built with the resources at hand.

56. **Clearing** may be taken at $10 to $50 per acre, or $20 to $400 per mile for timber varying from scattering to dense and widths of 16 to 60 feet.

57. **Earthwork.**—In a flat or gently rolling country where the road will mainly follow the natural surface with level cross sections, the side ditching and crowning may be taken at $350 per mile. In mountainous or rough country, with the road mainly in side cuttings, the grading and ditching may be taken at $350 to $700 per mile, the former for a lateral gradient or 15 to 1, and the latter for 5 to 1. For steeper lateral gradients, the cost will be greater.

58. **For embankments and cuttings in earth,** compute the volume of earth to be moved from Tables II or III and take the cost at 20 cents per yard plus ½ cent for each 100 feet of haul.

Cuttings and embankments in rock vary so widely in cost that any figure given as standard would be misleading in a majority of cases. Extensive rock excavations will rarely be undertaken in military road work.

59. **Metaling.**—For gravel, take $400 and for macadam $500 per mile for each inch of thickness.

60. Bridges and culverts must be estimated separately.

61. For a dirt road following the natural surface in level cutting the limit of cost may range from $500 to $2,000 per mile, depending on the character of soil, amount of clearing, and the number of bridges and culverts.

For a dirt road in side cutting the limits of cost may vary from $500 to $3,000 per mile, depending on the character of the soil, amount of clearing, number of bridges and culverts, and the lateral gradients.

Two thousand dollars per mile is used in estimating the cost of standard roads under average conditions in the Yellowstone National Park.

Macadam roads, usually called *stone roads*, have been built extensively in various States of the Union at costs ranging from $2,500 to $3,000 per mile. The figures here given as to metaling are based on a maximum width of 18 feet.

PART IV

RAILROADS

SEE

MILITARY RAILWAYS

PROFESSIONAL PAPERS NO. 32

CORPS OF ENGINEERS, U. S. ARMY

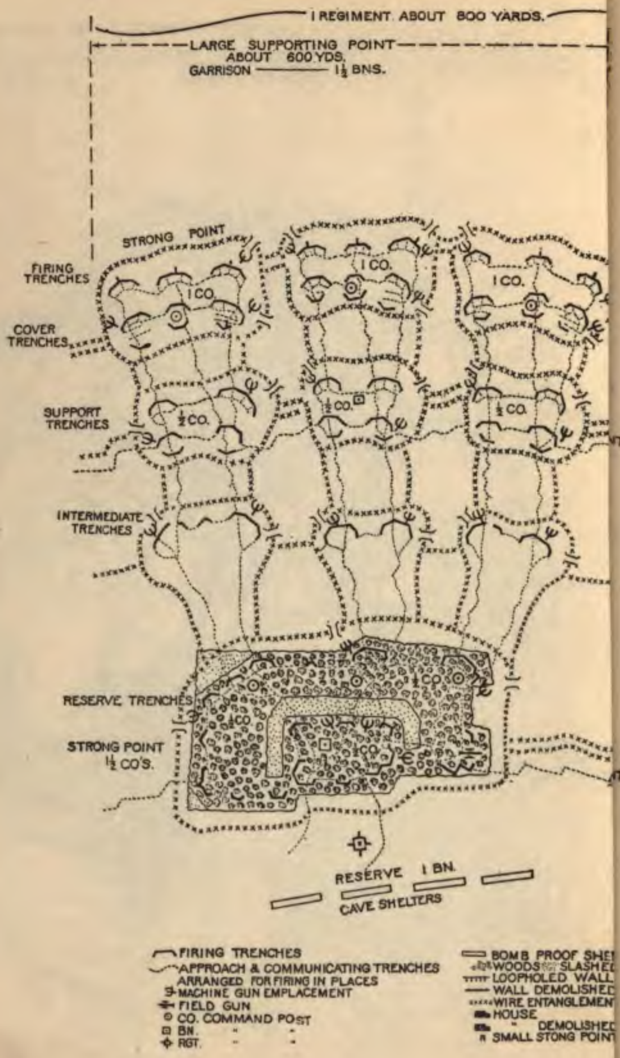
(REVISED 1916)

PART V

FIELD FORTIFICATION

INCLUDING

MINING AND DEMOLITIONS


I REGIMENT ABOUT 800 YARDS.
LARGE SUPPORTING POINT
ABOUT 600 YDS.
GARRISON — 1½ BNS.
STRONG POINT
FIRING TRENCHES
COVER TRENCHES
SUPPORT TRENCHES
INTERMEDIATE TRENCHES
1 CO.
1 CO.
1 CO.
½ CO.
½ CO.
½ CO.
RESERVE TRENCHES
STRONG POINT
1½ CO'S.
½ CO.
½ CO.
1 CO.
RESERVE 1 BN.
CAVE SHELTERS
FIRING TRENCHES
APPROACH & COMMUNICATING TRENCHES
ARRANGED FOR FIRING IN PLACES
MACHINE GUN EMPLACEMENT
FIELD GUN
CO. COMMAND POST
BN. " "
RGT. " "
BOMB PROOF SHE
WOODS SLASHED
LOOPHOLED WALL
WALL DEMOLISHED
WIRE ENTANGLEMENT
HOUSE
" DEMOLISHED
SMALL STONG POINT

PART V.—FIELD FORTIFICATION, INCLUDING MINING AND DEMOLITIONS.

1. **FORTIFICATION** is the art of increasing by engineering devices the fighting power of troops occupying a position. These devices have for their object to increase the effect of the fire action of troops protected by the fortifications and their mobility on the field, or to diminish the effect of the fire action of the assailant and his mobility.

2. **FIELD FORTIFICATION** deals with the preparation of such devices of a temporary character for immediate—not permanent—use, in a position which derives its tactical value from the incidents of a pending campaign and which may lose that value at or before the close of the campaign.

3. **The principal classes** of field fortification devices are:

Those which produce an **unobstructed field of fire** in front of the line of defense—clearings, demolitions, grading.

Shields or **shelters,** which protect the defender from the assailant's fire—trenches, galleries, redoubts, blockhouses, etc.

Masks, which **conceal** the defender from the assailant's view—plantations, embankments, screens, etc.

Obstacles, by which the advance of the assailant is retarded—abattis, slashings, entanglements, etc.

Facilities for communication for the defender—roads, bridges, telegraphs, etc.

Obstructions to communication of the assailant—destruction of bridges, obstruction of roads, obstacles, etc.

Many devices fall into more than one of the above categories.

4. Field fortification may be divided into **hasty intrenchments, deliberate intrenchments,** and **siege works. Hasty intrenchment** includes devices resorted to by troops upon a battle field to increase or prolong their fighting power, usually constructed in the presence of the enemy and in haste. **Deliberate intrenchment** comprises works constructed by troops not in line of battle for the protection of depots, lines of communication, supply, or retreat, etc. As they are usually intended to enable a small force to resist a much larger one, they are more carefully designed than hasty intrenchments and have greater defensive strength. **Siege works** comprise devices used by besiegers and besieged in the attack and defense of strong fortifications, and especially those devices which enable troops to advance under continuous cover.

The lines of division of the three classes are **not definite.** Some devices may belong to more than one class, and a work begun in one class may be merged into and be completed in another.

5. **COVER.—Protection from fire or view** is usually called **cover.** Protection from fire is divided into **horizontal** and **overhead** cover. **Horizontal cover** gives protection against direct or horizontal fire. It usually takes the form of a shot-proof barrier, vertical or nearly so. **Overhead cover** gives protection against indirect or high-angle fire, and against the fragments of shells and shrapnel bursting overhead. It ordinarily takes the form of a shot-proof barrier, horizontal or nearly so. Overhead covers are often referred to as **bombproofs** or **splinter proofs**—the latter if they are light, but proof against rifle fire or fragments of shell or shrapnel, the former if they are strong enough to resist the curved and vertical fire of siege guns and mortars. The term **splinter proof** is also ap-

plied to horizontal cover thick enough only to stop fragments of shell or shrapnel.

Unrevetted trenches even with side slopes as flat as 1 on 1 are sure to cave in. A good berm 18 inches wide and revetment are therefore essential. The minimum width at the bottom is 2 feet 6 inches, or better 3 feet, but 3 feet should seldom be exceeded; greater width reduces the protection too much. Revetted sides should have a slope of 4 on 1 or 3 on 1 and not be cut vertical. The depth from the top of the parapet to the floor board or bottom of the trench should be not less than 7 feet if possible. Height of parapet will depend on the site and the depth of the ditch for drainage.

6. **CONCEALMENT.**—Concealment depends primarily upon the nature of the terrain and local circumstances. Every artificial means, also, must be taken to hide trenches, gun emplacements, and other works. The aim should be to alter the natural surface of the ground as little as possible and to present a target reduced to the smallest possible dimensions. A newly constructed deep, narrow trench with low, wide parapet and parados is more visible to an air scout than the higher and narrower parapet of a shallow trench. Once the new earth is sodded the trenches lose their conspicuousness to a great extent. In rocky ground or on bottom lands, where the ground water is close to the surface, a trench with a high parapet is essential.

7. **PROFILES.—A profile** is a section of any cover made by a vertical plane perpendicular to its general direction or practically parallel to the direction of fire against and over it. Figure 3 is a profile on which the names of the component parts are indicated.

In dimensioning a profile the plane of site (supposed horizontal) is taken as the **plane of reference.** The distances of points of the profile from this plane are stated in feet and fractions—those above with the plus sign and those below with the minus sign. These quantities are inclosed in parentheses and are called **references.** Generally speaking, the plus quantities relate to embankments and the minus quantities to excavations. If the site is not horizontal, the plane of reference is assumed to pass through a point of the site vertically below the middle point of the interior crest.

8. **Command** has reference to difference of elevation; a higher point **commanding** a lower one; the latter **commanded** by the former. **"The command,"** used without qualification, means the **height of parapet,** or the elevation of interior crest above plane of site. The degree of command of one point over another may be expressed by the difference of elevation in feet, or better, by the gradient of the line joining them.

The relief of a parapet is the elevation of the interior crest above the lowest surface immediately in front—the bottom of the ditch, if there is one. With no ditch and a level site the relief and the height of parapet or command become the same.

The clear height behind the parapet will be referred to as **vertical cover.** It is the elevation of the interior crest above the bottom of the trench, or above the natural surface if there is no trench.

By the **thickness** of a parapet is meant the horizontal distance between the tops of the interior and exterior slopes. It is used as a measure of the **amount** of horizontal cover.

9. **The principal conditions** which determine the form of a profile of horizontal cover are the following:

The interior slope or breast height should be nearly vertical, and its height must correspond to one of the adopted firing positions, i. e., lying, kneeling, or standing.

The least thickness is regulated by the kind of fire against [illegible] ection is desired, as rifle, field, or siege artillery, and the [illegible]

[illegible] **rior slope** should have an inclination such that fire [illegible] allel to it will sweep the ground in front. **One-sixth** [illegible] d as **standard.**

[illegible] **slope** and the sides of trench and ditch should be [illegible] *ply of* material and the labor of placing it will permit, and the superior and exterior slopes should either be merged or make a small angle with each other. **The banquette slope,** if long, should be cut into steps to facilitate movement over it.

The quantity of **trench excavation** and of **embankment** should be nearly equal to minimize labor. This applies only to small parapets in which all the excavation is in a trench. For heavy parapets labor is saved by making the trench supply the inner part and taking the outer from a ditch.

The command should usually be kept as low as possible, for better concealment. For the same reason all sharp angles and hard lines should be avoided.

The thickness of ordinary earth required **to resist penetration** at usual battle ranges is 3 feet for rifle fire, 4 to 6 feet for field guns, and 15 to 20 feet for siege guns. It should be remembered that any protection is better than none. **Mere concealment** from view by a screen wholly inadequate to resist penetration will, for rifle fire especially, greatly reduce the casualties since the enemy's fire will be less rapid and less accurate if he can not see his target.

A narrow trench is desirable as it presents a smaller target. There must, however, be enough width to permit the construction of a firing banquette and of a certain deeper space at the rear part of the trench to allow men to pass behind the firing line. Also enough slope must be given the walls and the embankment work to prevent crumbling.

10. **THE MODERN RIFLE.**—The Springfield rifle, model 1903, adopted by the United States, is a good example of the type used by nations to-day. The caliber .30 pointed bullet weighing 150 grains has an initial velocity of 2,700 feet per second. The rifle is sighted for 2,500 yards and has a point-blank range of 550 yards. It is a clip loader and can fire at the rate of 20 shots per minute. This high-powered magazine rifle has a very flat trajectory (maximum ordinate 2 feet at 500 yards, 14.5 feet at 1,000 yards, 53 feet at 1,500 yards, 132 feet at 2,000 yards, 271 feet at 2,500 yards), thus giving very great danger space at all battle ranges.

The angle of fall of the bullet at 600 yards is about 1/115; at 1,100 yards, about 1/29; at 2,200 yards, about 1/4.75.

Rifle penetration.—The following table gives the approximate maximum penetration in various materials:

PENETRATION OF RIFLE BULLET.

	Inches.	
	200 yards.	600 yards.
Commercial steel	0.30	0.10
1½-inch broken stone, gravel	4.80	4.30
Hard coal between 1-inch boards	9.00	7.00
Brick masonry, cement[1]	2.20	1.20
Brick masonry, lime[1]	2.40	1.20
Sand, dry	9.00	12.00
Concrete, 1-3-5	3.00	2.00
Oak	27.00	12.00
Sand, wet	15.00	13.00
Pine	26.00	13.00
Earth, loam	20.00	16.00
Grease clay	60.00	32.00

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[1] For single shot: 150 rounds concentrated at one spot will break a 9-inch wall at 200 yards.

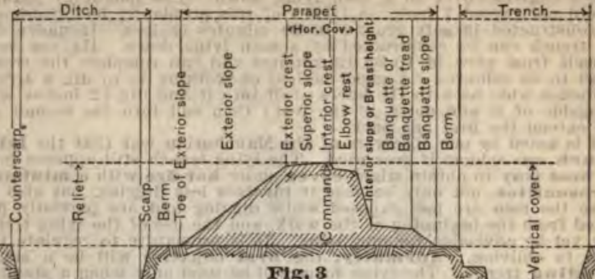


Fig. 3

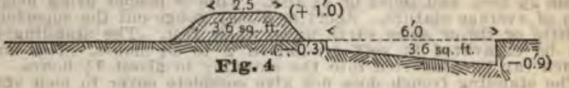


Fig. 4

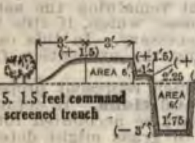


FIG. 5. 1.5 feet command screened trench

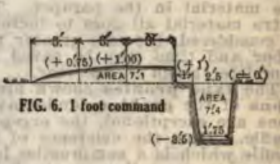


FIG. 6. 1 foot command

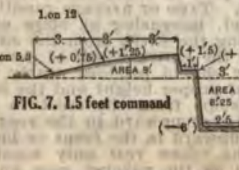


FIG. 7. 1.5 feet command

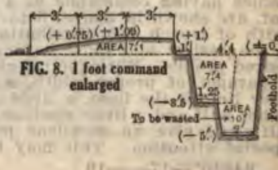


FIG. 8. 1 foot command enlarged

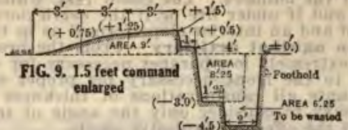


FIG. 9. 1.5 feet command enlarged

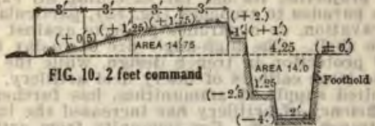


FIG. 10. 2 feet command

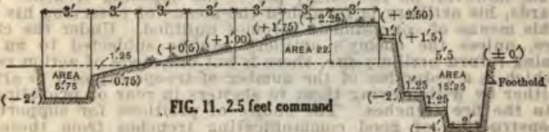


FIG. 11. 2.5 feet command

Narrow Firing Trench with Parados

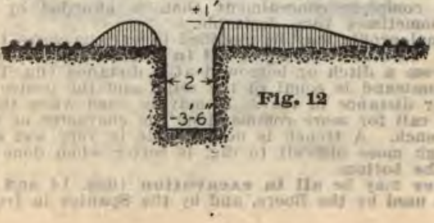


Fig. 12

may be cut after the parapet is finished, according to conditions and the preference of the builders. The elbow rest, while most desirable, is not essential, and if under fire or if the earth does not stand well it may be omitted and an interior slope formed as in the other profiles.

12. **Protection against artillery.**—From the preceding figures it is seen that the extremely low parapet necessary for concealment and the slight slope to the front necessary for proper sweep of ground practically eliminate all considerations of thickness of the parapet. It is thus necessary to consider only the angle of fall of projectiles and shrapnel and the effect of explosive shells.

The angle of fall of projectiles, considering them as just grazing the interior crest, has always been an important factor in designing trenches. Protection against artillery fire calls for very deep, narrow trenches. The effect of shrapnel may be lessened by recessing the trenches; while the effect of high-explosive shell may be greatly localized by providing numerous traverses and small parados. It might be noted that instead of by far the majority of shells being shrapnel, as was the case a few years ago, explosive shell has become the primary projectile, its use far exceeding all expectations. It is well to add a parados to trenches (fig. 12), particularly if there is an excess of excavation, as a parados protects against the back blast of high-explosive shell. The high-angle fire of to-day has increased the difficulties of protection in trench design, while the tendency toward the use of the large calibers of heavy field artillery, together with an almost unlimited supply of ammunition, has furthered these difficulties. The efficiency of artillery has increased the importance of concealment in trench design. For immunity from artillery fire, trench personnel must depend first upon presenting a target of great dispersion and little size, well concealed. Every natural and artificial means is taken toward this end, trenches having been placed even on the reverse slopes of hills with a field or fire of as little as 100 yards. As soon, however, as the enemy places his opposing trenches within 100 yards, his artillery is furnished the means of observing his shots, and this means of concealment becomes nullified. Under the circumstances, unless the enemy's artillery can be subjected to an overwhelming return artillery fire, there is but one mode of action remaining, which is a reduction of the number of troops exposed to artillery fire, either by withdrawing them to shelters in rear or providing dugouts in the fire trenches. The choice of positions for supports and the construction of good communicating trenches from these positions to the front line have, therefore, become of prime importance; while the necessity for obstacles sufficient to retard the enemy until supports can arrive in the front line has become equally so.

13. **Special profiles.**—**The advantages** of the normal profiles above described are that they produce a given cover with the least expenditure of time and labor, and that the first protection secured can be utilized as partial cover while enlarging and strengthening it. **The disadvantages** are that the effective cover is restricted to a narrow zone immediately in rear of the parapet, and that in wet ground or wet weather it is difficult to keep the trench reasonably dry. More complete concealment than is afforded by the normal profile is sometimes very desirable.

The normal profile may be modified in various ways to meet local conditions. **The cover** may be **all in embankment** and earth may be taken from a ditch or borrowed at a distance (fig. 13). In this form the command is equal to the relief and the protection extends to a greater distance in rear. It may be used when the conditions of the site call for more command or the character of the soil precludes a trench. A trench is not feasible in very wet soil, while a ditch, though more difficult to dig, is better when done for mud or water in the bottom.

The cover may be **all in excavation** (figs. 14 and 15). These forms were used by the Boers, and by the Spanish in front of Santi-

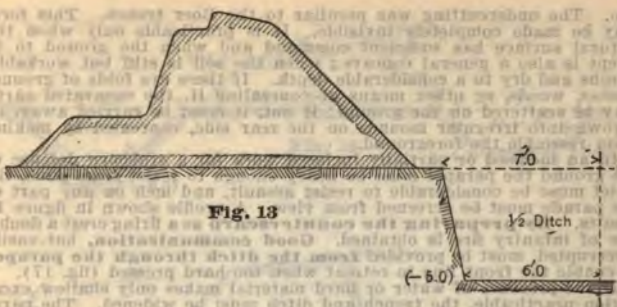


Fig. 13

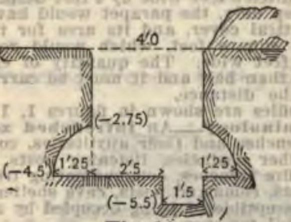


Fig. 14

Simple Standing Trench, Parapet Suppressed.

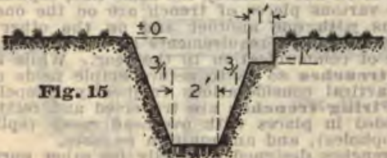


Fig. 15

age. The undercutting was peculiar to the Boer trench. This form may be made completely invisible. It is practicable only when the natural surface has sufficient command and when the ground to be swept is also a general concave; when the soil is stiff but workable, porous and dry to a considerable depth. If there are folds of ground, bushes, woods, or other means of concealing it, the excavated earth may be scattered on the ground; if not, it must be carried away, or thrown into irregular mounds on the rear side, concealed by making them resemble the foreground.

In an inclosed or partially inclosed work for a stubborn defense of the ground the parapet must be heavy enough to resist siege guns, the relief must be considerable to resist assault, and men on any part of the parade must be screened from view. A profile shown in figure 16 results. **By preparing the counterscarp** as a firing crest a double tier of infantry fire is obtained. **Good communication,** but easily intercepted, must be provided **from the ditch through the parapet** to enable the front line to retreat when too hard pressed (fig. 17).

If the presence of water or hard material makes only shallow excavation practicable, the trench and ditch must be widened. The parapet must be higher by the difference between normal and actual depth of trench, so that more material must be handled, and it must be moved farther.

For example, assume a parapet 6 feet high with a sectional area of 60 square feet to have a vertical cover of 10 feet. This might be dug from a trench 4 feet deep and 15 feet wide, or from a trench 10 feet wide and a ditch 5 feet wide by 4 feet deep. In soil which can be dug to 2 feet deep only, the parapet would have to be 8 feet high to give 10 feet vertical cover, and its area for the same horizontal cover would be 95 square feet, which would require excavating 2 feet deep and 47½ feet wide. The quantity of earth to be handled is greater by more than half and it must be carried, on an average, more than twice the distance.

Other special profiles are shown in figures 1, 18, and 19.

14. **Trench terminology.**—An **intrenched zone** consists of an entire system of trenches and their auxiliaries, composed of wire entanglements and other obstacles, listening posts, lookouts, machine-gun emplacements, fire trenches, communicating trenches, trenches for reserves and supports, command posts, cave shelters, latrines, and the like, occupied or susceptible of being occupied by a firing line and by its supports and local reserves.

Where several such zones exist, the one in occupancy or tactical use is called the first or frontal zone. The zone next in rear of the first is called the second zone, and so on. For convenience it may often happen that second or third zones are occupied by general reserves, just as it may happen that such reserves are utilized to construct such retired zones.

Firing trenches are those designated primarily for delivering rifle fire against an infantry attack. **Firing trenches** are ordinarily not continuous and often not in nearly the same line, especially in a hilly country, where various pieces of trench are on the one hand in defensive relations with one another and on the other conveniently located to meet their own requirements as to fields of fire, concealment, and ease of communication to the rear. While it is desirable to site **firing trenches** so as to secure ample fields of fire, nevertheless other tactical considerations frequently compel sacrifices in this respect. **Firing trenches** are traversed and relatively narrow. They are provided in places with overhead cover (splinter proofs), head cover (loopholes), and ammunition recesses.

Frequently trenches designed primarily for other purposes **(cover trenches, communicating trenches, approach trenches)** in places prepared for occupancy by a firing line, with appro- banquette, etc. Sometimes **approach trenches** may be pre-

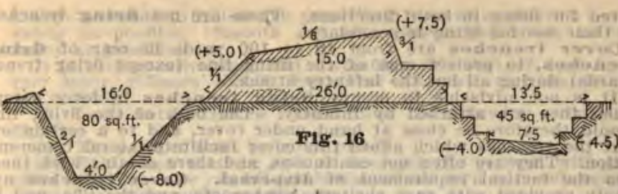


Fig. 16

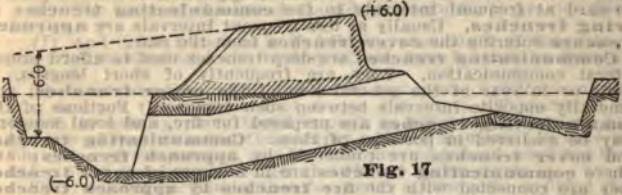


Fig. 17

Simple Standing Trench, Rocky Ground

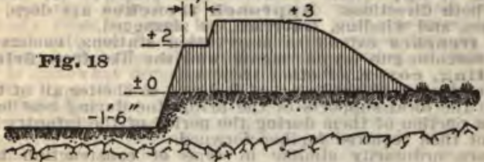


Fig. 18

Protection against Shrapnel

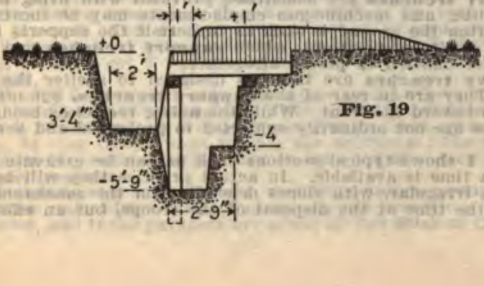


Fig. 19

always be made to follow the prescribed lines of excavation as accurately as possible. Smooth and even slopes and crests of visible rately as possible.

It is both an advantage and a standing rule that, if done by military labor, riflemen should themselves construct the trenches they are to hold.

15. Every **firing trench** should fulfill the following essential conditions:

(*a*) The parapet must be bullet proof.

(*b*) Every man must be able to fire over the parapet with proper effect; that is, so he can hit the bottom of his own wire entanglement.

(*c*) Traverses must be adequate.

(*d*) A parados must be provided to give protection against the back blast of high explosive shell.

(*e*) The trace of the trench should be irregular, to provide flanking fire.

(*f*) And if the trench is to be held for any length of time, the sides must be revetted and the bottom of the trench must be floored and drained.

The narrower the trench, the better the cover; but if too narrow it may hamper the movement of troops too much. Therefore a firing trench is usually made broad enough to allow of movement behind the line of men manning the parapet. Every man must be able to use his rifle over the parapet, and the men moving behind must not have to stoop down low in order to get their heads under cover.

The resulting section is, therefore, with a banquette or firing step 18 inches wide and 4 feet 6 inches (or 5 feet, if we allow for a small notch or hollow to hold the rifle) below the crest of the parapet, and behind this a deeper portion from 18 to 30 inches wide at the bottom and from 6 to 7 feet below the crest line of the parapet. The firing step must have a level surface to give a firm foothold. It may consist of an earth step revetted with planks held in place by stakes.

The best type appears to be a trench with a firing banquette for five or six rifles in each bay, between two traverses, each 6 feet thick, and with the back part of the excavation formed into a communicating trench for observation and manning of parapets. This trench is somewhat deeper and 3 feet wide.

Another type of firing trench has a minimum width of 28 inches, in order to afford the firer better protection; 15 to 20 yards in rear there is a second trench which permits communication and contains the shelters. The essential point in training is that one of these types should be adopted as the normal type suited to the local conditions, and the troops should be thoroughly trained in its construction.

16. **Communicating and approach trenches.**—Types are now becoming fixed, and in France the following seem to be the normal: Communicating and approach trenches well to the rear are 6 feet wide, those farther forward 3 feet wide, and both types 6 feet 8 inches deep. A communicating trench less than 3 feet wide at the bottom is sure to become jammed. This is the minimum to be allowed, and the work should be commenced with a width of not less than 3 feet 8 inches at the top, so as to get 3 feet at the bottom, according to the stiffness of the soil.

Berms of 1 foot on each side of a sap or trench where earth is piled up are considered indispensable. They prevent sliding of earth and furnish a little shelf on which to place tools, bags, guns, and other articles, in case troops want to pass the occupants; the double berm also makes it possible for infantry to leap out of a trench when the emergency requires.

17. **Earthworks** built entirely or largely **above ground** are used only when wet, ill-drained, or rocky ground compels. They afford good cover, and if the parapets are about 10 feet thick at the top, with

gentle front slope, and have had time to consolidate and dry out, they are said not to suffer much more from heavy artillery bombardment
removed when the loophole is in use.
than do the usual types of trenches with low parapets.

They are, however, very conspicuous, especially when new, and require great time and labor to build. They are much more comfortable for the troops sheltered behind them. The ditch excavation in front may be used as an obstacle and filled with wire. There should be at least a 2-foot berm at the foot of the exterior slope, so that this is not likely to fall into the ditch. Parapets of sandbags exclusively are much more vulnerable than those of earth and are of expensive material; they should be avoided except for minor works, such as blocking a trench toward the enemy, barricading a road, and the like. They may be used in emergency in the first zone if haste or silence is of paramount importance.

18. **Head cover** is the term applied to any horizontal cover which may be provided above the plane of fire. It is obtained by notching or loopholing the top of the parapet so that the bottoms of the notches or loopholes are in the desired plane of fire. The extra height of parapet may be 12 to 18 inches and the loopholes may be 3 to 3½ feet center to center.

Head cover is of limited utility. It increases the visibility of the parapet and restricts the field of fire. At close range the loopholes serve as aiming points to steady the enemy's fire and may do more harm than good at longer ranges. This is especially the case if the enemy can see any light through the loophole. He waits for the light to be obscured, when he fires, knowing there is a man's head behind the loophole. A background must be provided or a removable screen arranged so that there will be no difference in the appearance of the loophole whether a man is looking through it or not. Head cover is advantageous only when the conditions of the foreground are such that the enemy can not get close up.

Notches and **loopholes** (figs. 20–22) are alike in all respects except that the latter have a roof or top and the former have not. The bottom, also called **floor** or **sole**, is a part of the original superior slope. The sides, sometimes called **cheeks**, are vertical or nearly so. The plan depends upon local conditions. There is always a narrow part, called the **throat**, which is just large enough to take the rifle and permit sighting. From the throat the sides diverge at an angle, called the **splay**, which depends upon the field of fire necessary.

The position of the throat may vary. If on the outside, it is less conspicuous but more easily obstructed by injury to the parapet and more difficult to use, since in changing aim laterally the man must move around a pivot in the plane of the throat. If the material of which the loophole is constructed presents hard surfaces, the throat should be outside, notwithstanding the disadvantages of that position, or else the sides must be stepped as in figure 22. In some cases it may be best to adopt a compromise position and put the throat in the middle (fig. 22). Figures 23 to 26 show details and dimensions of a loophole of sandbags.

A serviceable form of loophole consists of a pyramidal box of plank with a steel plate spiked across the small end and pierced for fire. Figure 27 shows a section of such a construction. It is commonly known as the hopper loophole. The plate should be ⅜ inch thick if of special steel, or ½ inch if ordinary metal. Figure 28 shows the opening used by the Japanese in Manchuria and figure 29 that used by the Russians.

The construction of a notch requires only the introduction of some available rigid material to form the sides; by adding a cover the notch becomes a loophole. Various methods of supporting earth will be described under "Revetments." Where the fire involves a wide ateral and small vertical angle, loopholes may take the form of a

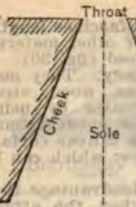


Fig. 20

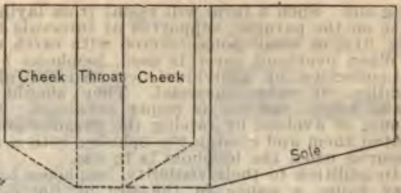


Fig. 21

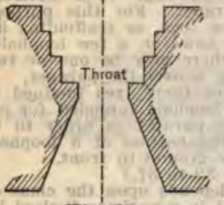


Fig. 22

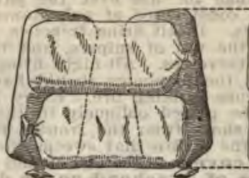


Fig. 23

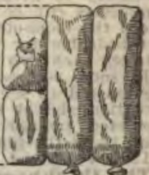


Fig. 24

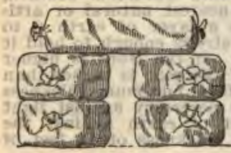


Fig. 25

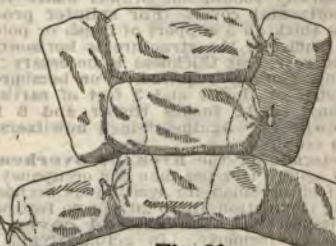


Fig. 26

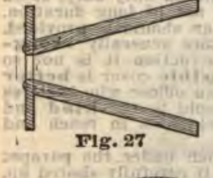


Fig. 27

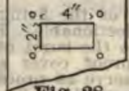


Fig. 28

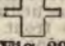


Fig. 29

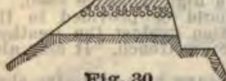


Fig. 30

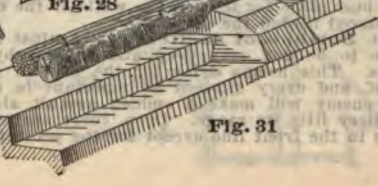


Fig. 31

long slit. Such a form will result from laying logs or fascines lengthwise on the parapet, supported at intervals by sods or other material (fig. 31), or small poles covered with earth may be used (fig. 30).

When overhead cover is used, loopholes are necessary. They may be collective or individual, constructed of sandbags, wood, steel, hurdles, or other material. They should be concealed by using grass, brush, canvas, or empty sandbags. The sky as a background should be avoided by raising the parados or placing a canvas curtain behind them and closing the opening with a metal cover which can be removed when the loophole is in use.

In addition to their visibility, loopholes have the disadvantage that they cause a pause in the fire of the defender when the attack reaches the most deadly zone of fire, because the defenders have to withdraw their rifles to prepare for bayonet fighting. It is therefore necessary to arrange for fire over the parapet. For this purpose banquettes can be constructed of sod, stones, logs, or scaffolding between the loopholes. In all firing trenches, however, a few loopholes are desirable for the use of snipers, and there may be one or two between each two traverses. All night firing is over the parapet.

In some sectors the loopholes should have their axes inclined to the normal to secure flanking fire. Every loophole intended for observation should be placed obliquely in the parapet in order to be protected against shots from the front. The bottom of a loophole must be in the plane of fire that sweeps the ground in front.

19. **Overhead cover.**—(See figs. 1 and 32 to 37.)

The thickness of overhead cover depends upon the class of fire against which protection is desired, and is sometimes limited by the vertical space available, since it must afford headroom beneath, and generally should not project above the nearest natural or artificial horizontal cover. For splinter proofs a layer of earth 6 to 8 inches thick on a support of brush or poles strong enough to hold it up will suffice if the structure is horizontal. If the front is higher than the rear, less thickness is necessary; if the rear is higher than the front, more is required. For bombproofs a minimum thickness of 6 inches of timber and 3 feet of earth is necessary against light field guns, or 12 inches timber and 6 feet of earth against the light howitzers. Against 6-inch howitzers a thickness of 12 feet of earth is required.

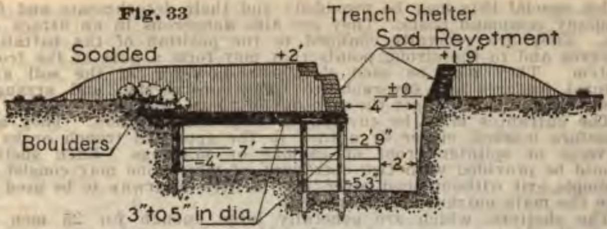
In determining the **area of overhead cover** to be provided, allow 6 square feet per man for occupancy while on duty only, or 12 square feet per man for continuous occupancy not of long duration. For long occupation 18 to 20 square feet per man should be provided.

The importance of **overhead cover** is more generally **recognized** than formerly. In actual trench construction it is not so difficult as it would appear. The **lightest possible** cover is **better than none.** Among the **first thoughts** of an officer who becomes responsible for intrenching a line of troops should be the **kind** and **quantity** of **material** for overhead cover which is in reach and how it can best be utilized.

Shelters in the front wall of the firing trench under the parapet made by undercutting are objectionable. Even if carefully shored up, they weaken the resistance to the burst of a high-explosive shell. A certain amount of splinter-proof cover should be provided in the front line, and it will also serve as protection against the weather. The best place for it is in the walls of the cover trench. It may also be placed behind the parados.

20. **Bombproof shelters** safe against heavy high-explosive shell have to be dug very deep and entered by a narrow opening and steps. This means delay for the men in getting out of the bombproof, and every moment is important in a well-planned attack, as the enemy will make a sudden assault almost at the moment the artillery lifts its range. Deep, cover shelters are therefore inadmissible in the front line except for the protection of machine guns (for

Fig. 33



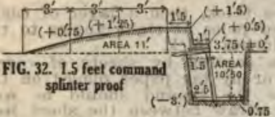


FIG. 32. 1.5 feet command splinter proof

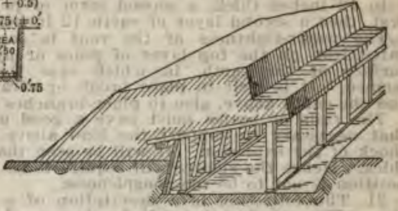


Fig. 34

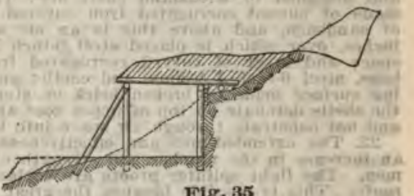


Fig. 35

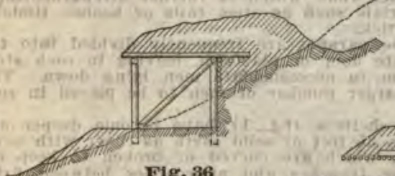


Fig. 36

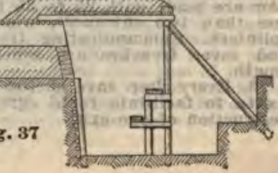


Fig. 37

which special lifts may be provided) and their detachments and for company command posts. They are also dangerous in an attack by gas. They are generally confined to the position of the battalion reserves and to the strong points that may form a part of the front system. They may be used elsewhere, however, if the soil and natural features are favorable to their construction and arrangements can be made to get the men out of them quickly.

The entrances must be covered to keep out splinters. They are therefore masked, either by a turn in the approach trench or by a traverse or splinter proof of gabions or sandbags. Each shelter should be provided with two entrances, of which one may consist of a simple exit without head cover, with a little stairway to be used in case the main entrance is obstructed.

The shelters, which are generally large enough for 25 men at most, should be constructed so that they will contain the men not on guard, half of them seated and half of them lying down.

The roof may be built as follows:

First a layer of poles 6 to 8 inches thick, then a layer of earth 8 to 12 inches thick, a second layer of poles at right angles to the first, then a second layer of earth 12 inches thick.

The water-tightness of the roof is secured by sheets of corrugated iron on the top layer of poles or by tar paper placed on the surface of the earth, in which case the ground should be well tamped. It is well to place brush or straw between the sheet iron and the earth above, also to place branches on the first layer of poles.

The rails or beams must have a good margin of strength beyond that necessary to support the load above them so as to stand the shock of the explosion. It will be seen that this roof is fully 6 feet thick. Hence the shelter will require to be at least 10 feet deep if its position is not to be too conspicuous.

21. The following is a description of a type of dugout construction. The construction of the dugouts has been carefully studied and designed to withstand shell fire: There is first a lower roof made of curved corrugated iron covered with two or three layers of sandbags, and above this is an air space of not less than 18 inches, over which is placed steel 6-inch I beams; then another air space and layer of curved corrugated iron, upon which are sandbags, steel 6-inch I beams, and earth; and on top of all a detonating surface made of broken brick or stone, the idea being to have the shells detonate on top of upper roof at the surface of the ground, and not penetrate through air space into lower roof before exploding.

22. The extended use and effectiveness of artillery fire demands an increase in the number and strength of shelters provided for the men. The light splinter proofs are replaced by shelters with strong roofs. This is possible because the great depth of the trenches furnishes earth for a thicker roof, which is further strengthened by layers of resisting materials such as steel rails or beams, timbers, plate iron, concrete, or brick.

The shelters under the parapet are frequently divided into two stories by an intermediate floor or platform, leaving in each story only sufficient head room to accommodate men lying down. This arrangement enables a larger number of men to be placed in relatively stronger shelters.

Underground or cave shelters (fig. 1) have become deeper and now are made with 25 to 35 feet of solid earth as cover with never less than two entrances, which are curved or broken to keep out splinters. Communicating trenches and approaches between firing and cover trenches are generally blinded throughout their whole length.

23. Every deep cave shelter must have **two or more separate exits** to facilitate rapid egress and to prevent a blockade by the destruction of one exit.

Roof timbers must always have three or four times the strength necessary to support merely the load due to the thickness of the roof. This allows for the shock of the shell as well as for the contingency that a new garrison may pile 2 or 3 feet more of earth on top of the existing roof.

A rectangular timber will support more weight if set on its edge than if set flat.

The ends of timbers should never be supported on sandbag walls or even direct on solid ground. A strong timber frame should always be used on two opposite sides of the shelter to support the ends of roof timbers.

24. A "burster" layer of 6 to 12 inches of brick or stone should always be provided near the top surface of the roof. Over this burster layer should be a layer of not less than 6 inches of earth to decrease danger from the scattering of the stone or brick by the burst of the shell. As the object of the burster layer is to explode the shell near the surface, it will be to a large extent defeated if the layer of earth above it is made more than 12 inches thick.

Cave shelters must be ventilated and the ventilator may be utilized for a periscope.

25. **Splinter-proof cover** is afforded by a layer of logs or beams 6 inches or more in depth covered over with not less than 12 inches of earth. The following forms a roof proof against a 6-inch high-explosive shell: A layer of rails or beams, 18 inches of earth, a layer of brick, 2½ feet of earth, another layer of brick 6 to 12 inches thick, and over all 6 inches of earth.

26. **Trace.**—In field fortification the term **trace** usually designates the horizontal projection of the interior crest. If the interior crest were traversed (see Reconnaissance), and the traverse plotted on paper or on a map, the result would be the trace. As a general rule the trace of a parapet will follow the lines of best natural cover or those which determine the strongest natural position. In practice it usually happens that the troops are located with a view to taking full advantage of the features of natural strength, and the fortifications are thrown up where they are to give them additional protection.

The interior crest should be horizontal, and hence the crest should, as a rule, follow a contour. Generally a broken line will approach the contour near enough and will be easier to lay out and construct. If the contour curves sharply, the trace should curve also. Angles must be rounded off to make them less conspicuous, and at the beginning and end of a trench its bottom should gradually rise and the parapet fall to nothing for better concealment.

The particular contour to be chosen depends upon local conditions. Figure 38 is a section or profile of a ridge perpendicular to the general direction of its crest. The summit of the ridge *T* is called the **topographic crest.** The contour corresponding to the point *M* is the one from which all the ground in front can be seen and reached by fire and is called the **military crest.** The sky line is variable in position. From the point *G* the sky line is at *D*. From *E* the sky line is at *F*.

In locating a line of trench it is important—

(*a*) To avoid a sky line;
(*b*) To occupy the military crest or a line in advance of it; and
(*c*) To preserve communication under cover with the rear.

If the ridge is steep and is intersected by ravines or covered with growth through which men could move under cover, a position near the foot of the slope, as *G* (fig. 38), might be better, as a plunging fire, besides being more difficult to deliver, is not so effective as a fire parallel to the ground. Such a line would not be the main line of resistance and would not as a rule be reenforced. A reserve line should be constructed on the military crest and provision made for withdrawing the men from the front line under the best cover possible when it can no longer be held.

27. **Kinds of trace.**—Fieldworks are classified by the form of their trace into **open, half-closed,** and **closed works.** An **open work** is one affording cover on the side of the enemy's approach only, with no preparation to resist flank or rear attack. It may consist of a line or of lines disposed in a geometrical figure. A line of trench, like a line of men, depends upon adjacent parts of the line to protect its flanks. Ends of a line retired, as in figure 39, give a fire in front of adjacent trenches for flanking support.

Lines of strong profile have a **dead space** in the ditch or close in front of the parapet which, if the work is to stand assault, must be swept by flank fire. Adjacent works may be made to bear on this ground, or a line may be made self-flanking by giving it the trace shown in figure 40. The long lines may be 200 to 300 yards long or even longer. The short line should not be less than 12 yards long, and their crests should be held lower than the rest. Lines are always in the class of open works.

The dead space may be avoided by adopting a form of profile called the **triangular,** shown in figure 41. The disadvantages of this profile are the additional labor of construction, the diminished thickness of the upper part of the parapet, and the comparatively slight obstacle to escalade presented by the flatter slope. A flanking fire will usually be preferred to the triangular profile.

28. **A redan** consists of two lines called **faces,** *ab* and *ac* (fig. 42), which make an angle of about 60°. This angle is called the **salient;** its bisecting line *ad* the **capital,** and the line *bc* the **gorge.** The redan is mainly used to secure a flanking fire along a line of parapet or a cross fire on important ground.

The exterior angle at *a* between the faces prolonged is dead space which must be denied to the enemy by obstacles or covered by fire from adjacent works, or the angle may be truncated, as shown by the full line in figure 42. Such a disposition is a **pan coupé.** The pan coupé, if short, can deliver but a small volume of fire. The truncation may be made by a broken reentrant line, as shown dotted in the figure. This form is called a **priest cap.** A redan is usually open, but may be made a half-closed work by placing obstacles across the gorge.

29. **A lunette** (fig. 43) consists of four lines, two of them, *ab* and *ac*, called **faces,** and the other two, *bd* and *ce*, called **flanks.** The angles at *b* and *c* are called **shoulder angles.** The salient, capital, and gorge are as in the redan. The salient angle is at least 120°, which gives an effective fire on every part of the foreground and a good flanking fire as well.

The lunette is the simplest trace adapted for use in an isolated work. It may be open or half closed. In a half-closed work, either redan or lunette, the **gorge defense** may consist of obstacles or of a low trench, or of the two combined. In any case, a road must be left through it for communication. This road may be closed by a gate or removable barricade or may be swept by fire from a short trench inside the gorge.

A gorge trench should have a double parapet, the front one serving as a parados to protect men in the trench from shots coming from the main line and also as a firing line to command the interior of the lunette in case the enemy gets in over the front. The gorge profile (fig. 44) is a type.

30. **Redoubts** are works entirely inclosed by defensible parapets, though the term **fort** is usually applied to such a work when it has unusual strength, either by reason of its trace or its armament. In the former case a word descriptive of the trace is often added, as **star** fort (fig. 45), **bastioned** fort (fig. 46).

The inclosed form and the restricted and usually crowded interior space make redoubts excellent targets for artillery, and they can not be used in situations exposed to such fire unless they can be so arranged that they can not be recognized as redoubts from the enemy's artillery positions. A favorable site is one which commands the

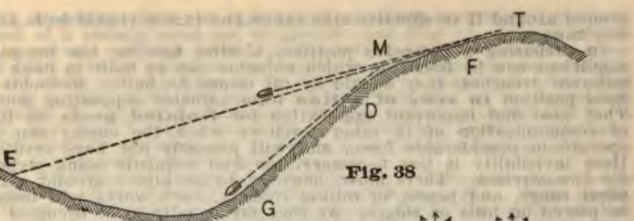


Fig. 38

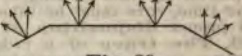


Fig. 39

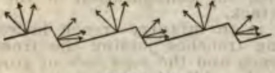


Fig. 40

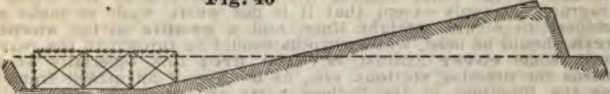


Fig. 41

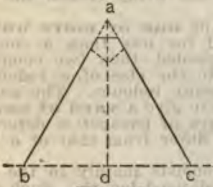


Fig. 42

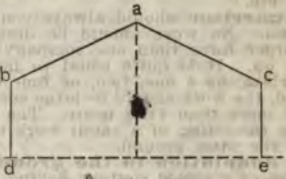


Fig. 43

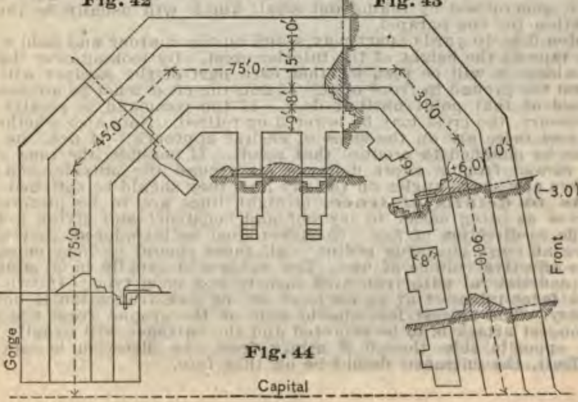


Fig. 44

ground around it to effective rifle range and is not visible from artillery ranges.

In preparing a defensive position, if sites meeting the foregoing conditions can be found on which redoubts can be built to flank the adjacent trenches, they should by all means be built. Redoubts in good position **in rear of a line** form valuable supporting points. They also find important application for **isolated posts** on lines of communication or in other territory when the enemy can not operate in considerable force, and will probably not have artillery. Here invisibility is less necessary, the first requisite being security for the garrison. There must, however, be no higher ground within short range, and hence, in rolling country, such works will usually be placed on hills or ridges. As they are usually to be occupied for some time, care must be taken that a **supply of water** is available and proper **disposition of refuse** provided for.

31. **The trace** of a redoubt will depend upon the size of the garrison to be accommodated, the configuration of the ground, and the probable direction of attack.

The **simplest redoubt** is an infantry trench inclosing the area selected, with communicating trenches joining the front face which corresponds to the firing trench and the rear face or gorge which corresponds to the cover trench. All the instructions for siting in paragraph 20 apply except that it is not worth while to make any sacrifices to secure straight lines, and a **profile** giving **surplus earth** should be used, which surplus should be thrown to the rear to obtain some **cover** against **reverse fire;** this especially at the returns for dressing stations, etc., as in case of an attack from the rear the functions of the various parts are reversed; that is, the cover trench becomes the firing trench, the firing trench the cover trench, etc.

The garrison should always consist of **one or more units** of command. No work should be designed for less than a company. If a larger force than one company is needed, then two companies, and so on. It is quite usual to indicate the size of a redoubt by its garrison, as a one, two, or four company redoubt. The garrison assumed, the work should be large enough to give a **yard of parapet** for not more than **two men.** The length of parapet is determined first, as the siting of a small work may differ from that of a larger one on the same ground.

The adaptation to the ground consists mainly in the determination of a closed contour having the desired length. Such a contour, generalized by taking out small kinks, will usually be the best location for the parapet.

Men 5 to 10 yards apart may stand on the contour and hold a tracing tape at the height of the interior crest. By looking over the tape all along, it will be seen whether each part of the parapet will command the ground in front of it. If not, the crest must be advanced or raised at that point until it does. If the command is greater than necessary, the crest may be lowered or retired. Note also whether the longest faces are on the sides of easiest approach. If not, the trace must be modified to produce that result. If possible, the tape should be viewed from a short distance all around the outside, and if it makes any sharp angles on the sky line, they should be softened.

As to details of trace, straight lines are to be preferred to curves as being easier to lay out and construct and giving a better guide to direction of fire. If curves must be introduced, they should have at least 20 yards radius. All faces should be long enough to give effective volume of fire. Ten yards will usually be a minimum. A quadrilateral with truncated corners is a good type. If two adjacent faces intersect at an angle of 30° or less, truncation is not necessary. The longest face should bear on the ground from which the strongest attack is to be expected and the entrance will usually be on the opposite side, though if attack from any direction is especially difficult, the entrance should be on that face.

32. **Profile.**—So far as regards the effectiveness of its fire, the command of a redoubt need not be greater than that of a trench on the same ground. A high command will better screen the interior space and offer greater resistance to assault, but will increase the visibility of the work and the labor of building it. The horizontal cover need not, as a rule, be as thick as the adjacent trenches, as the latter will certainly be exposed to deliberate artillery fire and the redoubt, as a rule, will have to resist unaimed and scattering artillery fire only. **A necessary feature** is a trench deep and wide enough to give complete shelter and free communication.

33. **Interior arrangements.**—The most important thing is the protection of the garrison from flank and reverse fire. When invisibility is not essential, a command of 6 or 7 feet is the easiest method of giving interior protection. Extensive overhead cover will be necessary. It need not ordinarily be heavy. Six inches of earth on brushwood stiff enough to support it will usually suffice. When long-range fire may be expected from the front only, the overhead cover will be developed along the front edge of the trench of the front face, in excavations perpendicular to the trench on the flanks, and along the edge of the trench opposite the parapet in the gorge.

Figures 47 and 48 show an infantry redoubt recently built at Fort Riley, Kans., for test purposes. It embodies some of the latest approved features of such works.

There is a tendency to limit the use of redoubts to the strengthening of key points. In other situations their depth must be restricted as much as possible, so that the redoubt resembles a trench of unusual strength. Overhead cover will always be an important feature.

For a possible all-round long-range fire, short galleries should be run out to the rear of all trenches. This development of covered trenches may continue, if necessary, until the entire interior of the redoubt is converted into an underground camp. The parapet trenches and the shelters in them must be well traversed, the former by blocks of earth with oblique or crooked passages cut through them, and the latter by splinter-proof partitions of brush and earth.

Figure 44 shows a typical plan, with sections, of a redoubt on level ground, where a command of 7 feet is permissible.

34. **Modern developments.**—Rather than revolutionizing the art of battle-field fortification, the experience on the west front in Europe shows that deliberate permanent fortifications with their cupolas, concrete parapets, magazines, and prepared gun emplacements have given way to line upon line of intrenchments and earthwork inconspicuous as possible, manned by an ample number of mobile troops thoroughly trained in trench warfare, with artillery of all calibers, but mobile and easily concealed. The extent and the strength of the positions that have been prepared in northern France entail an attack upon them which approximates to regular siege operations, while the war, as carried out along the east front and in the Balkans, approaches closer to field conditions that would exist in our country.

Although the principles of field fortification or field intrenchment have not changed, there are many extensions, adaptations, and new applications of existing principles which have been developed in the European war.

35. The developments to be noted are due to the following main causes:

(*a*) Improvement in artillery; longer ranges; heavier projectiles; high-explosive shells; special use of shell and **shrapnel** in demolishing earthworks and cutting wire entanglements; vast number of guns and enormous expenditure of ammunition; skillful indirect fire.

(*b*) Improved methods of observation and communication; balloons, airplanes; photography from aircraft; telephones, wireless telegraphy; motor transportation.

(*c*) Continuous intrenched positions with unassailable flanks.

(*d*) Long-continued occupancy of field works at all seasons of the year.

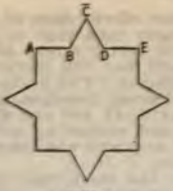


Fig. 45

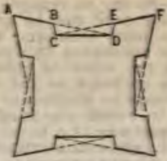


Fig. 46

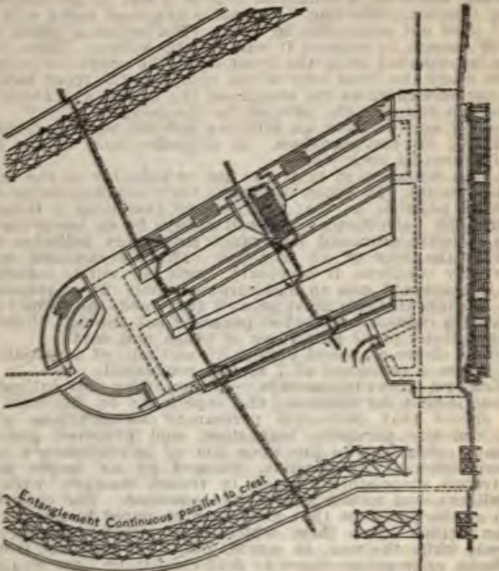


Fig. 47

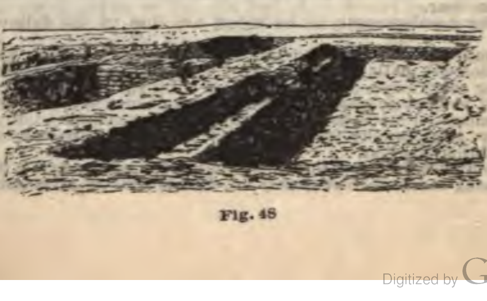


Fig. 48

(*e*) The construction of intrenched positions in localities of great diversity as to topography, character of soil, geology, vegetable growth, and drainage.

(*f*) The close proximity of the opposing lines of trenches.

(*g*) The use of new devices and methods of attack, such as grenades, trench mortars, poisonous gases, inflammable liquids, intense artillery bombardment, barrier fire, machine guns in great numbers, and many accessories developed as the result of the continual reaction between the attack and the defense.

The most conspicuous changes that have resulted in field fortification are:

(*a*) Less extensive field of fire.

(*b*) Greater importance and corresponding greater difficulty of concealment, involving use of screens, dummy trenches, hidden emplacements, and covered approaches.

(*c*) Deeper and narrower trenches.

(*d*) Greater use of traverses and parados in firing trenches.

(*e*) The use of many support and cover trenches generally parallel to the firing trench, and not very distant therefrom.

(*f*) More numerous communicating and approach trenches, screened and defiladed, forming, with the firing, cover, support, intermediate, and reserve trenches, a labyrinth of trench work known as the "first intrenched zone."

(*g*) Increased use of cover.

(*h*) Provision of shelter for men in cover, support, intermediate, and reserve trenches, and in deep underground bombproofs or "cave shelters," safe against powerful artillery fire; less safe shelters in the walls of the cover and support trenches and sometimes in the firing trenches.

(*i*) Extensive use of strong points and supporting points in the first intrenched zone.

(*k*) Provision for the defense of the communicating and approach trenches against flank attack by hostile forces that may have broken through the front lines.

(*l*) A second intrenched zone some two or three miles in rear of the first zone, generally on the reverse slope of a crest or ridge, and connected with the first-zone trenches by sheltered approaches, natural or artificial.

(*m*) Intrenched zones still farther to the rear for possible occupancy in case of defeat or retirement.

(*n*) Increased use of obstacles, especially barbed-wire entanglements.

(*o*) Increased use of mines and countermines.

(*p*) Accessory special measures to prevent surprise and to resist special methods of attack.

(*q*) Systematic measures to prevent confusion and going astray of troops moving in the maze of trenches, by day and by night such as guide posts, lights, maps, names of approaches and shelters.

(*r*) Routine measures of maintenance, convenience, and comfort due to the long-continued occupancy of the trenches, such as revetment, drainage, heating, food supply, water supply, ammunition supply, and sanitation.

36. **General considerations.**—The proper use of shelter trenches for the protection of firing lines is a matter of utmost importance to success. It may be accepted as a principle, established by experience, that a line of men can not remain stationary under fire without cover, natural or artificial. This is true in every phase of action, whether advancing, retreating, or standing on the defensive. Cover at all times is desirable; on the move it may be dispensed with, at a halt never. In some cases the cover will be partly natural and partly artificial, i. e., partial natural cover artificially improved. In a majority of cases, however, conditions of fire efficiency and concealment will require a line to be placed where it could not possibly live without artificial cover. Another principle

utes materially to cleanliness. They are also useful for building small covered observation stations along the parapets.

40. **Timber or pole revetment.**—In case of long continued occupancy of the trenches, revetments of timber and plank will gradually replace the lighter forms, and boards and gratings will be used to floor the bottom of the trenches.

Poles too large for use in any other way may be cut to length and stood on end to form a revetment. The lower ends should be in a small trench and have a waling piece in front of them. There must also be a waling piece or cap at or near the top, anchored back. Figure 62 shows this form.

41. Some of the forms of temporary revetments are:

Gabion.
Sod.
Sandbag.
Brushwork.
Wire netting hurdle.
Continuous hurdle work.
Expanded metal.
Continuous wire mesh.

42. **Gabion making.—A gabion** is a cylindrical basket with open ends, made of brush woven on pickets or stakes as described for hurdles. The usual size is 2 feet outside diameter and 2 feet 9 inches height of wattling. On account of the sharp curvature somewhat better brush is required for gabions than will do for hurdles.

The gabion form (fig. 58) is of wood, 21 inches in diameter, with equidistant notches around the circumference, equal in number to the number of pickets to be used, usually 8 to 14, less if the brush is large and stiff, more if it is small and pliable. The notches should be of such depth that the pickets will project to 1 inch outside the circle. The pickets should be 1¼ to 1¾ inches diameter, 3 feet 6 inches long, and sharpened, half at the small and half at the large end.

To make a gabion, the form is placed on the ground, level or nearly so, and the pickets are driven vertically in the notches, large and small ends down, alternately. The form is then raised a foot and held by placing a lashing around outside the pickets, tightened with a rack stick (fig. 59). The wattling is randed or slewed from the form up. The form is then dropped down, the gabion inverted and the wattling completed. If the brush is small, uniform, and pliable, pairing will make a better wattling than randing. If not for immediate use, the gabion must be sewed as described for hurdles, the same quantity of wire being required.

The gabion, when wattled and sewed, is completed by cutting off the tops of the pickets 1 inch from the web, the bottom 3 inches, the latter sharpened after cutting, and driving a carrying picket through the middle of its length and a little on side of the axis. See that the middle of this picket is smooth. Three men should make a gabion in an hour.

Gabions may be made without the forms, but the work is slower and not so good. The circle is struck on the ground and the pickets driven at the proper points. The weaving is done from the ground up and the entire time of one man is required to keep the pickets in proper position.

If brush is scarce, gabions may be made with 6 inches of wattling at each end, the middle left open. In filling, the open part may be lined with straw, grass, brush cuttings, or grain sacks, to keep the earth from running out.

43. **Gabion revetment.**—The use of gabions in revetments is illustrated in figure 61. If more than two tiers are used, the separating fascines should be anchored back. Gabion revetments should be crowned with sods or bags.

The advantages of the gabion revetment are very great. It can be put in place without extra labor and faster and with less exposure than any other. It is self-supporting and gives cover from view and partial cover from fire quicker than any other form.

Several forms of gabions of other material than brush have been used. Sheet iron and iron and paper hoops are some of them. The iron splinters badly, is heavy, and has not given satisfaction. If any special materials are supplied the method of using them will, in view of the foregoing explanation, be obvious.

44. **Sod revetment.**—A convenient size to cut sods is 18 by 9 by 4½ inches. If tough, they may be cut larger, but the length should be twice the breadth. They are laid grass down in courses, alternately all headers and all stretchers, the latter double, with broken joints. A bed should be prepared at the proper inclination to receive the bottom course and give it the right pitch. The top course is laid grass up and all headers. If the sods show a tendency to slip, they may be pinned together with wooden pickets.

Sod revetments will not stand quite so steep as sand bags in the same soil. It is usual to allow a 3 to 1 slope for sods. The revetment should be built steeper, if the soil is such that it will stand. Figure 54 shows an elevation and section of a sod revetment.

Four sods, 18 by 9 by 4 inches, laid, make a square foot of revetment, but as there is some wastage, 450 or more sods must be cut for each 100 square feet of surface to be revetted. If the grass is long, it should be mowed before cutting sods.

One man should cut 30 sods per hour, or place the same number. A sod plow will cut as fast as 50 men.

If carrying is done by hand, multiply the number of sods to be moved per hour by the average length of carry in yards and divide the product by 7,500 for the number of carriers. They should work in pairs, carrying 8 sods between them. If wagons are available, estimate as though moving earth (see Roads), taking 72 sods to the cubic yard. Unloaders will be required, as the sods can not be dumped, say one man for 300 sods per hour. If ordinary sodding is to be done, for concealment or to prevent rainwash, use the same ratios for cutting, hauling, and laying, allowing 8 sods to the square yard laid, or 9 cut.

45. **Sand-bag revetments.**—A sandbag is 33 inches long and 14 inches wide. In use it is loosely filled with earth or sand, requiring about ½ cubic foot of earth, and having been placed in position is flattened with a shovel to roughly rectangular form, in which it fills a space about 20 by 13 by 5 inches. The bags weigh about 62 pounds per 100, and when filled about 65 pounds each.

A sand-bag revetment is constructed by laying the filled bags as stretchers and headers, or as headers alone. The top row should always be headers. The tied ends of headers and the seams of stretchers should be in the parapet. Sandbags give no splinters, and are conveniently used for the entire parapet when necessary. As they are more readily transported than corresponding quantities of any other revetting material, they are of great importance in field fortification. Their perishability is a disadvantage, though in many soils a surface revetted with bags will stand after the bags have lost their strength through decay. Sandbags are so valuable for crowning and repairs, however, that the stock on hand should not be exhausted in original construction if anything else can be had.

Figure 49 indicates the appearance of a sand-bag revetment as seen from the front and from the end.

Sandbags are laid as headers, i. e., the length of the bag at right angles to the face of the revetment or as stretchers, i. e ., the length of the bag in the plane of the face of the revetment. The revetment should slope at an angle of 4/1, and therefore the ground on which the bottom layer or course is laid should be at a slope of 1/4. The sandbags must be bonded, i. e., the bags of each course must break joint with the bags of the courses above and below. A certain number of headers must be used to tie the revetment into the bank. It is usual to lay sandbags with one header to every two stretchers.

When filling sandbags the bottom corners must be well tucked in, and it helps if the mouth of the bag is turned over for about 3 inches. The bag then stays open more easily. Bags should be three-fourths full, and care must be taken to obtain uniformity in this, for unless the bags are all the same size they will not build up readily. A sandbag when filled should measure 20 by 10 by 5 inches.

The line of revetment must be prepared by digging a notch with the bottom at a slope of 1/4 and broad enough to take a header. Since the header is 20 inches long the back of the notch should be 5 inches below the front. If the face of the revetment is kept at right angles to the bottom of this notch, the required slope of 4/1 will be obtained.

In laying the bags the mouths of the bags should be folded over underneath the bags. The mouths of the headers and the seams of the stretchers should be turned in toward the back, so that if the bag becomes untied or the seams burst the earth will not fall into the trench. The bags should be beaten with a spade, maul, or shovel into a rectangular shape, otherwise the bags do not get a firm seating. The face of the revetment should be quite smooth and not lumpy. Unless it is certain that the revetment is not to be extended, the ends should be left irregular so that any extension will be bonded to the existing revetment. It is best to finish off the parapet of a firing trench with a row of headers.

Rate of working.—A squad of 6 men, 2 shovels, 1 pick, 1 bag holder, and 2 tiers should, in fairly loose soil, fill 150 bags an hour.

Supposing the bags to be filled from the ditch or trench, with 10 additional men, 6 to carry and 4 to lay, or a squad of 16 men all told, 150 bags per hour can be taken care of, making 75 square feet of revetment.

46. **Brush work.**—Brush is used in many forms in revetting. Any kind will do, but the best is willow, birch, ash, hickory, or hazel. For weaving it must be live, and is most pliable when not in leaf. Split bamboo of pliable dimensions, reeds, or similar vegetation may be considered as a form of brush in all revetment constructions.

Brush for weaving should not be more than an inch in diameter at the butt. That to be used straight may be of larger size. In cutting, brush should be assorted in sizes for the various uses and made up in bundles of 40 to 60 pounds, the butts in one direction. The range of weights is given to convey a general idea of the size of bundles. The determining condition is that each bundle shall make a gabion, which will soon be determined after work begins. Poles of 2½ inches diameter at the butt or larger are not bundled, but are piled together. They are used for posts, binders, grillage, and similar purposes.

The amount of labor required to cut brush will vary with its character, whether hard or soft, crooked or straight, thick or thin. A rough average may be taken at six bundles per man per hour. The men work in pairs, one cutting and one sorting, piling, and tying.

For carrying by hand, multiply the number of bundles by the carry in yards and divide by 2,200 for the number of men required. If transportation is by teams, assume 35 bundles to equal 1 yard, and figure as for earth.

47. **A fascine** is a cylindrical bundle of brush, closely bound. The usual length is 18 feet and the diameter 9 inches when compressed. Lengths of 9 and 6 feet, which are sometimes used, are most conveniently obtained by sawing a standard fascine into two or three pieces. The weight of a fascine of partially seasoned material will avera[illegible] pounds.

[illegible] re made in a **cradle** which consists of five trestles. A t[illegible] made of two sticks about 6½ feet long and 3 inches in d[illegible] ven into the ground and lashed at the intersection as [illegible] e 51. In making a cradle, plant the end trestles 16 feet [illegible] allel. Stretch a line from one to the other over the [illegible] e the others 4 feet apart and lash them so that each [illegible] es fairly to the line.

To build a fascine, straight pieces of brush, 1 or 2 inches at the butt, are laid on, the butts projecting at the end 1 foot beyond the trestle. Leaves should be stripped and unruly branches cut off or partially cut through, so that they will lie close. The larger straighter brush should be laid on the outside, butts alternating in direction, and smaller stuff in the center. The general object is to so dispose the brush as to make the fascine of uniform size, strength, and stiffness from end to end.

When the cradle is nearly filled the fascine is compressed or **choked** by the **fascine choker** (fig. 52), which consists of two bars 4 feet long, joined at 18 inches from the ends by a chain 4 feet long. The chain is marked at 14 inches each way from the middle by inserting a ring or special link. To use, two men standing on opposite sides pass the chain under the brush, place the short ends of the handles on top and pass the bars, short end first, across to each other. They then bear down on the long ends until the marks on the chain come together. Chokers may be improvised from sticks and rope or wire.

Binding will be done with a double turn of wire or tarred rope. It should be done in 12 places, 18 inches apart, the end binders 3 inches outside the end trestles. To bind a fascine will require 66 feet of wire (see Bridges).

Improvised binders may be made from rods of live brush; hickory or hazel is the best. Place the butt under the foot and twist the rod to partially separate the fibers and make it flexible. A rod so prepared is called a **withe.** To use a withe, make a half turn and twist at the smaller end (fig. 53), pass the withe around the brush and the large end through the eye. Draw taught and double the large end back, taking 2 half-hitches over its own standing part (fig. 54).

When the fascine is choked and bound, saw the ends off square, 9 inches outside the end binders. After a cradle is made, 4 men can make 1 fascine per hour, with wire binding. Withes require 1 man more.

A fascine revetment is made by placing the fascines as shown in figure 55. The use of headers and anchors is absolutely necessary in loose soils only, but they greatly strengthen the revetments in any case. A fascine revetment **must always be crowned** with sods or bags.

48. In all brush weaving the following terms have been adopted and are convenient to use:

Randing.—Weaving a single rod in and out between pickets.

Slewing.—Weaving two or more rods together in the same way.

Pairing.—Carrying two rods together, crossing each other in and out at each picket.

Wattling.—A general term applied to the woven part of brush construction.

49. **Brushwood hurdles** are usually made 6 feet long and of the required height. The pickets should project 18 inches below the brushwood and be sharpened for driving into the ground. They should be about 3 inches in diameter and should be spaced approximately 2 feet apart; that is, four pickets to a hurdle. Actually the two outer pickets should be about 6 inches from the ends of the hurdle. The pickets are therefore 1 foot 8 inches apart. The brushwood should be 1 to 1½ inches in diameter and of ash, willow, or other pliable wood.

To construct the hurdle, drive the pickets into the ground firmly, and 18 inches from the bottom of the pickets run two strands of plain wire along the pickets, taking a turn round each picket. Twist these wires together until they are quite tight, then weave the brushwood in and out of the pickets, beginning at the bottom and keeping it pressed firmly down on the wire. Each length of brushwood should pass alternately in front of and behind the pickets, and if a piece of brushwood is behind the picket the piece next on top should be in

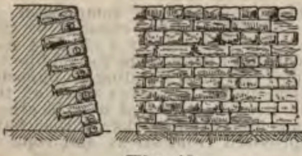


Fig. 49

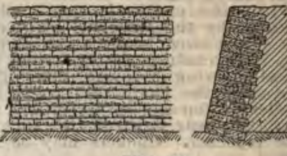


Fig. 50

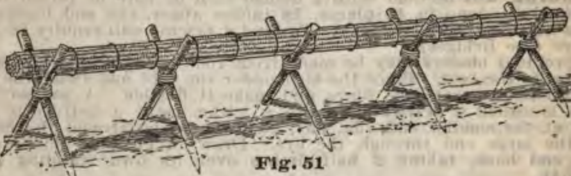


Fig. 51

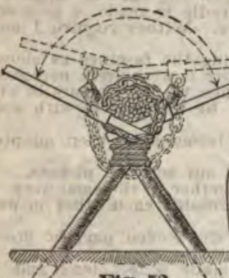


Fig. 52

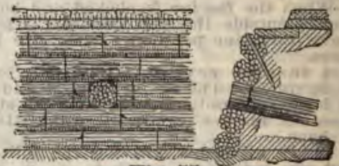


Fig. 55

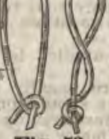


Fig. 53

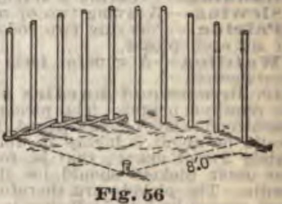


Fig. 56

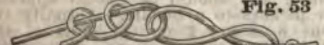


Fig. 54

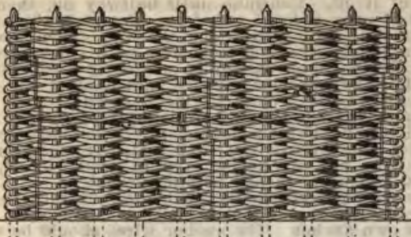


Fig. 57

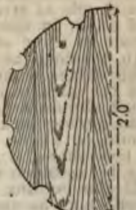


Fig. 58

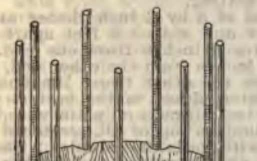


Fig. 59

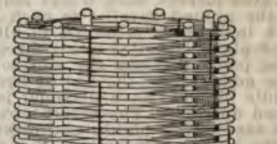


Fig. 60

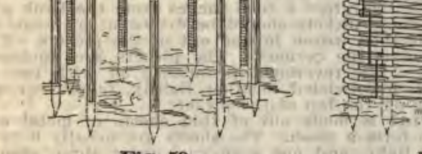


Fig. 61

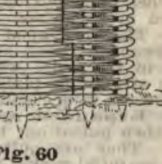


Fig. 61a

front of it, and so on. If the brushwood is not long enough to reach the length of the hurdle, twist another piece to it or tie a piece to it with wire. It is seldom possible to bend a piece of brushwood round the end picket and take it back along the hurdle, so let it project about 6 inches and cut it off. Continue until halfway up, then put in a couple of strands of wire, twisted as before. Complete the hurdle and finish in the same way with wire along the top. Then sew the hurdle in three or four places from top to bottom with plain wire.

In placing the hurdle the bank should be cut away to a slope a little flatter than 4/1. The hurdle should be laid against the bank and the pickets driven into the ground 18 inches. The top of each picket should be anchored back by 6 to 8 strands of plain wire to a stout anchor picket, driven firmly at a good slant. The anchor picket should be about 3 feet long and driven in 2 feet. It should never be less than 10 feet from the revetment, even in good ground, and may be as much as 30 feet away in bad holding ground.

If the holding power of the ground is good, all four pickets of a hurdle may be anchored back to one anchor picket. If very bad, each picket may require its own anchor. The anchor wires should be windlassed up tight. The anchor wires should be fastened to the anchor picket at ground level and to the hurdle just above the brushwood.

50. **Rabbit wire hurdles.**—The following is perhaps the best way of using rabbit wire or poultry netting.

Three pickets, each 6 feet long and of 3 by 2 inch timber are laid on the ground parallel to each other and spaced 3 feet apart. A 5 by 1 inch plank is nailed to all three 6 inches from one end. Another plank is nailed to all three 18 inches from the other end, and a third plank dividing the gap between the other two. Diagonals are then added from the top of each outer picket to the bottom of the middle picket. Each diagonal is of two strands of plain wire, windlassed up tight. The rabbit wire is laid on top of all, stretched tight, and fastened to planks and pickets with nails and staples. The ends of the pickets, projecting 18 inches, are sharpened for driving. The anchor wires are put on the pickets close to the top plank and another 5-inch plank is then nailed on flush with the tops of the pickets.

51. **Continuous hurdle work.**—In this case the bank is cut back to a slope of 4/1, stout 8-foot pickets are driven in every 2 feet 6 inches or 3 feet, with their feet 4 to 6 inches from the bank and driven in 18 inches. These pickets should be driven at an angle of 4/1. The brushwood is then woven in and out of the pickets. The brushwood is bent around the corners. The pickets are anchored back in the usual way. The revetment is finished off with two or three strands of plain wire, twisted together tightly, to prevent the brushwood from coming off the top of the pickets.

52. **Expanded metal** is made out of thin sheets of metal slit and then pulled out to form a mesh. The sheets are usually 6 by 3 feet. They are quite light, and one man can carry three sheets. This material makes a good revetment. It is best to carry it up to the trenches already made up into panels.

Put two sheets of metal edge to edge and overlapping to such an extent that the sheets together make up the requisite height of the revetment. The overlap should not be less than 6 inches. Sew the two sheets together strongly with plain wire. Take three light poles 1½ to 2 inches in diameter and lay them on the metal parallel to the long edge of the sheets, one near the top, one near the bottom, and one in the middle. Sew these poles to the metal with plain wire, starting and finishing 9 inches from the edge of the metal, thus leaving a length of 9 inches at each end of each pole not attached to the metal. The panel can then be rolled up and carried into the trench.

To construct the revetment, cut the bank back to a slope of 4/1. Lay the panels against the bank—the poles horizontal, the panels overlapping—that is, the edge of the metal of one panel is slipped between the poles and metal of the next panel. The poles will then overlap 9 inches and the metal will overlap 9 inches behind them. Take good 8-foot pickets 4 inches in diameter and drive them on a slope of 4/1 tight against the panels, one at each overlap and one between the overlaps. Anchor back in the usual way.

In getting round traverses the horizontal poles must be omitted and the panels cut vertically from the top about three-fourths of the way down. One-half is then allowed to slide behind the other, thus keeping the slope of 4/1.

53. **Continuous wire mesh revetment.**—Use slightly lighter pickets 2½ inches to 3 inches in diameter. Cut the bank back to 4/1. At intervals of 2 feet to 2 feet 6 inches cut vertical grooves in the bank big enough to take a picket. Drive a picket with its foot in the bottom of each groove. Do not drive in more than 6 inches and let the picket stand a few inches clear of the bank.

Then at the bottom, halfway up and about 6 inches below the top of each picket, run two or three strands of plain wire twisted up taut. The bottom strands should be put on first, then the middle, then the top so as to avoid loosening of the wires already put on by overtwisting the next ones. Then run diagonals of similarly twisted wire from the top of each picket to the bottoms of the pickets on both sides. Where the diagonals and horizontal wires cross in the middle of the panels join them together with a short piece of plain wire. This gives a framework to hold the rabbit wire.

Run the rabbit wire behind the framework—that is, between the framework and the bank. Pull it as tight as possible and attach it to the framework in many places with short length of plain wire. Put on the anchor wires and draw the poles up against the bank. Then drive the poles tight home. Tighten up the anchor wires so as to draw the poles into the grooves. The rabbit wire is then brought tight against the bank.

54. **Traverses.**—The protected area in rear of a parapet as determined for a shot grazing and perpendicular to the crest, is reduced for a grazing shot with the same angle of fall coming at an angle to the crest. If a straight shot will clear a man's head at a certain distance back, oblique shots with the same angle of fall will clear a man at 90 per cent of that distance for an angle of 26° with the perpendicular, 85 per cent for 32°, and 80 per cent for 37°. At 37° the distance is decreasing at the rate of 1 per cent for each degree. For enfilade and reverse fire the parapet gives no cover at all.

To secure sufficient protection against very oblique, enfilade, or reverse fire and to localize effect of exploded shell, masks must be introduced to intercept such shots before they fall below the plane of desired protection. Such masks are called **traverses.** To those which are designed to intercept reverse fire, and which are mainly parallel to the parapet which they shelter, the name **parados** is given. The word **traverse** usually indicates a mask making an angle with the parapet which it protects and joined to it. Traverses may be of any available horizontal or overhead cover, but are usually topped with earth. They are revetted to make them take as little space along the parapet as possible, except that between guns there is sometimes room for earthen traverses with sloping sides. As the lower part can not be reached by fire, it need only form a support for the top and is often a good place to provide magazine or shelter space.

Distance between traverses.—The effective distance is the interval between the crest of one traverse and the adjacent face of the next. If the crests of the traverses are at the same elevation as the crest of the parapet, a distance between traverses of 0.43 of the width of protected area, for direct fire, preserves 90 per cent of that width; 0.52, 85 per cent, and 0.6, 80 per cent.

If the crests of the traverses are **raised above** the crest of the parapet, the distance between traverses may be increased by the excess height multiplied by the assumed angle of fall, without reducing the width of the protected area (fig. 65). Figure 66a shows a plan and side elevation of a raised traverse, with reference to its connection with the parapet. The full lines show relations when the crest of the traverse ends at the interior crest, and the broken lines indicate the arrangement when the crest of the traverse extends beyond the interior crest. Care must be taken that raised traverses do not make the position conspicuous. Traverses must be **at least as long** as the width of protection they are to give, and should be somewhat longer.

Profile of traverses.—The cross section of a traverse should be as nearly a rectangle as possible. The vertical sides give the maximum thickness with the minimum space, and the flat top gives a crest on each face and increases the interval by half the thickness (fig. 63). If exposed on one side only the profile in figure 64 is suitable.

A traverse may be used as a firing parapet by providing a banquette or steps at the proper height.

55. **Types of traverses.**—A trench may be traversed by making an offset to the rear, as shown in figure 66, and throwing up a bank of earth on the block left. Figure 66b shows a form of double traversing. The long high traverses afford protection to men not firing, and the short traverses give increased protection to the more exposed space near the interior crest. For high traverses, the object should be to get a support up to the height where exposure to fire begins with the least time and labor. If the structure can be made hollow, so much the better. An elevated platform of planks, supporting a parapet of earth, revetted with sods or sand bags, will make a good traverse. If earth is the only material available, the entire traverse will be revetted (figs. 62 and 63). Below the plane of fire any revetment may be used; above, only those which have been described for crowning a parapet revetment should be employed.

56. Traverses must be strong and solid and when possible should consist of the undisturbed earth. They should be from 2 to 4 yards thick and should overlap the width of the trench by at least 1 yard, and should be well revetted. The clear distance between traverses is that necessary to accommodate a small number of rifles, say those of a squad of five to eight men; the distance therefore is from 5 to 8 yards. (See fig. 1.)

Traverses in a trench facilitate bombing attacks along its length by an enemy who may have entered it as grenades can be thrown from under cover of a traverse into the second compartment beyond. A longer compartment to prevent this may be occasionally placed in the line of the trench. This long bay should be straight, and the traverses on either end should be loopholed for fire into it. Bombing trenches or pits behind the front line are also useful to stop this form of attack.

Where traverses have to be built in a completed trench insufficiently traversed, they must be made in embankment using the earth excavated to form the passage round the traverse and supplementing it with sandbags or other revetting material.

42. For approach trenches the best type is the "**island traverse**" with the trench going round it on both sides. Sections of trench subject to special exposure are sometimes protected with "bridge traverses," built across the top of the trench on supports of timber or steel.

57. **Stockades.**—A stockade is an improvised bullet-proof wall or screen, usually adapted to defense by rifle fire. As compared with a parapet, the **advantages** of a stockade are that it combines obstacle and parapet, gives good cover and ample interior space, and the labor of construction increases less rapidly with the height. **The disadvantages** are the uncertainty of procurement of suitable material, the labor of construction, which is greater than for a parapet, except for considerable heights, and that most forms of stockades afford no cover, and the best of them only temporary cover, from artillery.

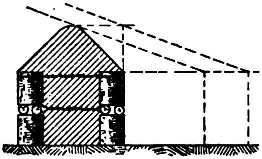


Fig. 62

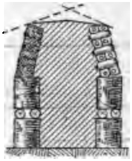


Fig. 63

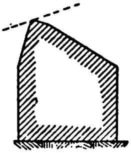


Fig. 64

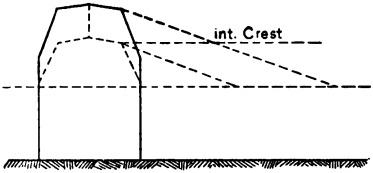


Fig. 65

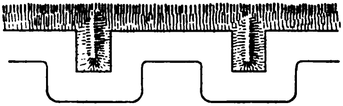


Fig. 66

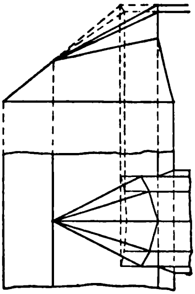


Fig. 66 a

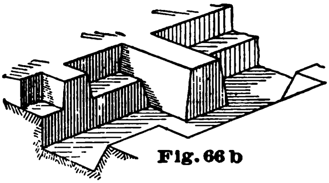


Fig. 66 b

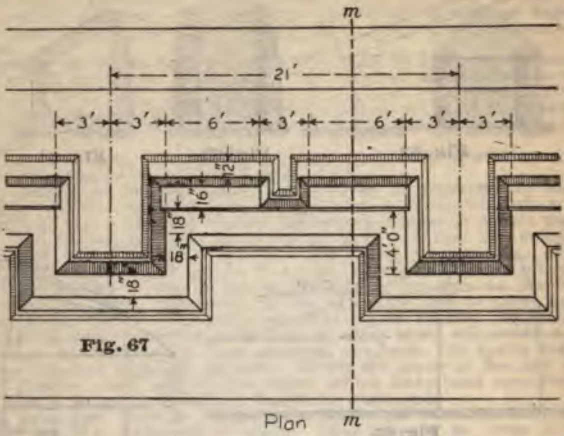
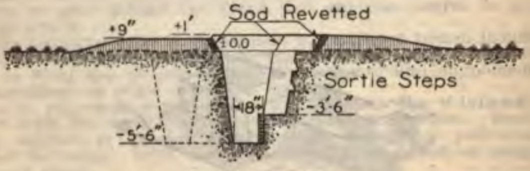


Fig. 67



Section m m

Fig. 68

Construction.—The simplest form consists of a closed barricade of timbers loopholed and reenforced by earth (figs. 70 and 71). The inner embankment forms a banquette. The outer one fills the dead angle at the foot of the wall and is some protection against artillery fire. It makes a stockade easier to scale, but if the slope is steep and the tops of the timbers properly prepared by driving spikes or stringing barbed wire, the effect in that direction is small.

A single row of timbers affords too little protection unless they are squared or great pains taken to keep close joints. A double row (fig. 73), or if the logs are good size and workable, an arrangement of half timbers (fig. 74) gives the same cover with much less labor. Loopholes may be formed as indicated. They must be high enough so that the enemy can not fire through them when he comes to close quarters. Six feet above the ground is considered high enough.

A single row of timbers may be used as the front of two thin walls, the space between to be filled with earth or broken stone (fig. 69), or both walls may be alike, and of brush, plank, fascines, or sheet iron (fig. 72). Earth filling should be 2 feet thick; stone filling 6 to 16 inches.

In all such constructions the two walls must be tied together at frequent intervals to resist the pressure of the filling. Wire is a very convenient material for such use. If T rails are available, an excellent stockade may be made as shown in the figure 75.

58. **A blockhouse** is a room or small building with bullet-proof walls, weather- proof and fireproof roof, loopholed for infantry, often for machine guns, and sometimes for light quick-firing guns. The walls may take any of the forms described for stockades, or may be of masonry. The roof will usually be of tin or sheet iron. If exposed to plunging fire, the roof may take the form of light overhead cover, and to promote the comfort of the garrison during long occupancy an ordinary roof may be placed over the earth, or it may be covered with canvass, or thatched, or made to turn water in any practicable manner. Figures 76 to 79 and 83 show types of blockhouses. In figure 79 the house provides 2 tiers of fire.

Extensive use was made of blockhouses by the British in South Africa. Some, at important points, were of masonry, presenting no unusual features. By far the greater number were of double skins of corrugated iron, filled between with broken stone. The first built were about 10 by 15 feet in plan with the skins on separate frames or supports 2 feet apart. Then an octagonal form was introduced with both skins on the same frame, leaving but a few inches between them. A difficulty experienced with this form was that a shot striking opposite a timber of the frame would penetrate the entire structure, as it would encounter no stone. A construction permitting stone to be placed behind each timber in the path of a shot passing through it was introduced, but was complicated and difficult. The final and most satisfactory design was circular in plan. A corrugated-iron drum 13½ feet in diameter and 3 feet 11 inches high was set on level ground and a parapet of stone, 3 feet thick at bottom and 2 feet at top, was built around it on the outside. On this parapet was placed a shield consisting of an inner drum of corrugated iron 15 feet in diameter and an outer one 16 feet in diameter, each 2 feet 3 inches high, and kept at uniform distance by spacing blocks at the top.

The loopholes, 12 in number, of sheet iron of the double-hopper type, with throats 6 inches high by 3 inches wide, were placed in the shield, the bottoms 4 feet 3 inches from the floor. The space between the skins of the shield was filled with closely packed broken stone. It was found necessary to provide for adding stone under the loopholes to replace settlement. An octagonal frame rested on top of the shield and was bolted to the spacing blocks, its alternate sides extended to complete a square on which a pitch roof was built. A canvas roof, supported by a pole, like a conical tent was used in some cases.

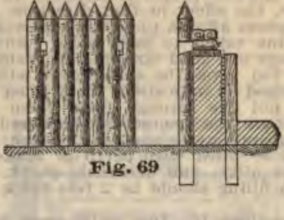


Fig. 69

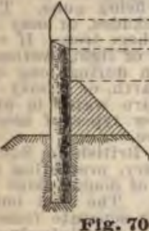


Fig. 70

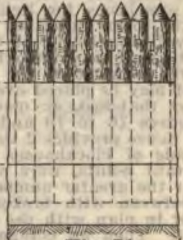


Fig. 71

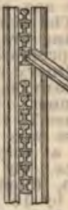


Fig. 75

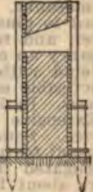


Fig. 72

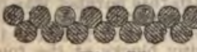


Fig. 73

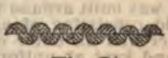


Fig. 74

A small opening on one side, large enough for a man to crawl through, was closed by an iron door under the outer drum of the shield. There was also a removable barrier of the same construction as the shield, which stood against the opening in the drum of the parapet.

A trench 4½ feet deep was dug 2 to 5 yards outside the blockhouse and a wire entanglement was constructed outside the trench. Such blockhouses were sometimes built at the rate of 6 a day by a party of 30 men. Nearly 400 of these were erected, most of them in a single month.

59. **Flanking defenses.**—Dead angles in front of a defensive structure may be swept longitudinally or parallel to the firing crest to prevent their being used as a rallying place by the assailants. Such fire is usually directed along the front from one of the flanks and is called **flanking fire.** The structures built for this purpose are called **flank defenses.**

A **caponiere** or **tambour** is a small, low, stockaded inclosure or blockhouse situated to fire along a dead angle. If it can be placed at the intersection of two dead angles it may sweep both. At the foot of a wall a stockade open at the top may be used, if its floor must be at ground level, which will be the case on rock or marsh, though a weatherproof cover will generally be desirable (fig. 81). If the floor can be sunk below the ground level, a bullet-proof roof is necessary (fig. 82). In a ditch the structure should be sunk so that the roof will be below ground level and the top should be of overhead cover. It must not extend entirely across the ditch, or if it does, or nearly so, it must be obstructed so that it can not be used as an approach.

There must be communication through and under the parapet or wall, so that the defenders in the tambour can escape into the interior at the last.

60. **A ditch** may also be flanked by a **counterscarp gallery,** which is a bomb-proof chamber formed behind or outside of the counterscarp at the salient of a parapet (fig. 80). The side toward the ditch is stockaded and loopholed for fire along the ditch. The entrance must be on the ditch side and protected from fire. The garrison of a counterscarp gallery will usually have no communication with the interior of the work.

61. **Obstacles** are designed to protect the works from surprise and to reduce the momentum of attack by breaking up the enemy's formation and holding him under the accurate fire of the defense. They should be **invisible** from the direction of approach, should be **difficult to destroy,** and should afford **no screen or cover** to the enemy.

Obstacles may be in front of or on the line of defense. In the former case they should be 50 to 100 yards in front of the firing crest. If on the line, they are in the ditch, if there is one, or are employed to close intervals and are flanked or enfiladed by adjacent works.

Obstacles should be at such distance from the parapet that it is difficult for hostile bombers to crawl up to them and then throw bombs into the trench. On the other hand, the obstacles should be under close observation and under close fire of the defense. If the front edge of the wire is 40 yards from the trench, these conditions are fulfilled.

62. **Concealment.**—The value of an obstacle will be increased and its liability to injury by fire decreased if the obstacle is concealed. If it is possible to place the obstacle in a fold in the ground, so much the better. It is sometimes possible to place the obstacle in a broad, shallow ditch. In that case the deepest part of the ditch should be toward the enemy. The earth should be carried back and placed in the parapet.

63. **Construction.**—The obstacle should be made in such a way that the following conditions are fulfilled:

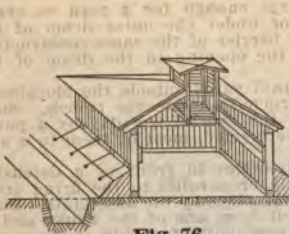


Fig. 76

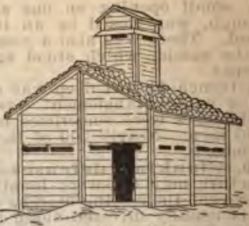


Fig. 77

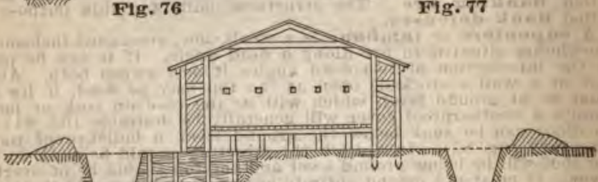


Fig. 78

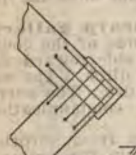


Fig. 80

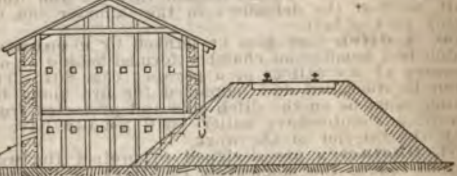


Fig. 79

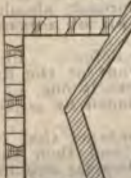


Fig. 81

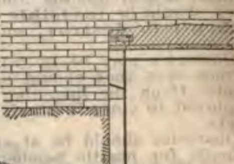


Fig. 82

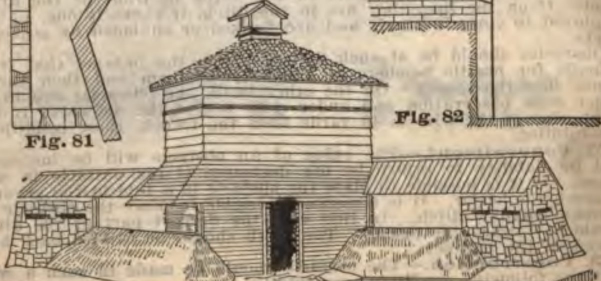


Fig. 83

(1) The working party constructing it should be extended and never bunched together.

(2) Silence must be preserved. Therefore, everyone must know exactly what he has to do.

(3) Speed is necessary. The work must therefore be methodical, each man having a specific task.

(4) The working party must never have an obstacle between it and the trench.

(5) The obstacle should be one that can be improved and thickened up easily and quickly.

(6) The obstacle should be of a type that will suffer as little as possible from hostile gun and small-arm fire and from rifle and machine-gun fire of the defense.

64. **Above all in importance as an obstacle is wire entanglement.**—Under the conditions of the war in Europe no trench is found worthy of the name that has not been protected by this means. About 50 feet in front of trenches an entanglement, usually 30 feet wide, is placed, though often trenches may be protected by two similar lines of entanglement 50 feet apart. As many as three lines are sometimes used. As for the wire, it is barbed if possible, but often smooth and of every possible diameter; it has been necessary to make use of any kind that could be obtained. In a number of cases abatis may also be used in front of the trenches. In the early part of the war all roads leading to Paris were barricaded at frequent intervals near the city; some of these barricades at the gates of the city were protected by a ditch, wire entanglement, chevaux de frise, and abatis, in the order stated. In front of many lines of open trenches barbed wire to the extent of 50 miles to the mile of front has been used, while around fortified places the use of 400 miles of wire to the mile may be cited.

65. **Wire chevaux de frise.**—A form of portable wire entanglement consists of three or four wooden crosses, lashed or spiked at their centers to a long pole, such as a bean pole, and connected with each other by barbed wire. This produces an obstacle similar to a chevaux de frise, and presents a barbed-wire fence, even though rolled over (figs. 84 and 85). There is also another smaller individual chevaux de frise prepared in trenches and used for throwing forward into one's own entanglement to make it more complex or to be carried while making the assault to throw into the enemy's trenches to prevent circulation therein. These latter are constructed on a stick some 5 or 6 feet long, with two 2-foot crosspieces toward one end. This frame is firmly draped with barbed wire, forming a polyhedral mass with a short free end of the long stick for a handle.

66. **Construction of wire entanglements.**—In constructing entanglement, wooden or iron posts may be used. A very good type of iron post is about three-quarters inch in diameter, provided with eyelets for attaching the wire, and has the lower end auger twisted for about 18 inches, so that it can be screwed securely into the ground. The construction of entanglement in the face of the enemy has always been attended with great losses, so that the possibility of using the auger post noiselessly at night is a great advantage.

The impracticability of constructing regulation entanglement under fire has led to what might be termed sectional installation. One such method is to prepare, under cover, panels some 15 or 20 feet long, of wire firmly fastened to the pointed stakes and then rolled up. Soldiers provided with mauls rush out in front of the trenches, carrying the panels, which they unroll on the way, and, arriving on the line of the proposed entanglement, they quickly drive the stakes. The ends of wire purposely left extending beyond the stakes at the ends of each panel serve to bind the panel to the next erected by other soldiers. It is not a single line of entanglement like a fence that is thus built, but several lines, joined by a multiplicity of triangles and squares. For rapid and noiseless placing of entanglements, one of the manuals of this war provides as follows: Triangular pyramids

3 feet 6 inches high are made of six poles or pieces of timber. These pyramids are used in pairs, with six wires connecting them. In any position of the pyramids the wires will be up. Each pyramid can be carried by one man. The bays are taken out and placed on the ground so as to break joints, and are later picketed down if occasion offers (fig. 86). Another substitute for posts consists of three sticks crossed at right angles, bound together at their middle points, and the ends wired in triangles.

67. **Wire for entanglements.**—The commercial package of barbed wire in a coil is not convenient for carrying or working along the trenches. It is therefore wound by soldier labor on sticks a yard in length and a couple of inches thick. The winding is done in a sort of a figure 8 and results in an eliptical ball about a foot thick, from the ends of which the stick protrudes, affording two handles for carrying and manipulation. In many places specially made wire is employed, which is much heavier than the commercial barbed wire, and the barbs are themselves much heavier and more closely placed. The ordinary barbed wire, while it can be more easily obtained, does not, of course, give the protection that is obtained with the special wire. Much of this special heavy wire with 4-point barbs at inch intervals has been used, and when once in place is most efficacious, but it is so difficult to handle that for hasty installation the preference is for the commercial wire with a hand's width between barbs.

68. **Construction of low wire entanglement.**—The party should consist of 32 workers if possible, exclusive of noncommissioned officers. Form the party in two ranks and number them in threes both front and rear rank. The left file is not numbered. For the sake of explanation letters are given to these parties of three as follows:

o o o   o o o   o o o   o o o   o o o
B   D   F   H   K

o o o   o o o   o o o   o o o   o o o
A   C   E   G   I

Assume that two bays of low wire are to be built.

Description of obstacle.—The obstacle consists of 3 foot 6 inch pickets driven about 1 foot into the ground. At the end of each row of pickets is a short anchor picket sloping back away from the line of the entanglement and about 3 feet from the end pickets. The rows are 3 yards apart and the pickets in each row are 3 yards apart. The pickets are placed in quincunx order; that is, those of the middle row divide the gaps between those of the outer rows. A taut strand of barbed wire is run along each row at knee height, being made fast with a round turn to each picket. Between the middle row and each of the outer rows is a diagonal wire, taut and at knee height, running from the first outer row picket to the second center row picket, the second outer row picket, and so on.

Resting on the diagonals and half way between the rows of pickets are laid two wires, one on each side of the center row, quite loose so that they loop about on the ground. These loose wires are fastened to the diagonals by twisting the loose and diagonal wires together in every other place that they cross.

Duties of parties.—Parties A and B go out almost simultaneously. Party A drives the first row of pickets and so needs a maul. The maul man should be tall. One man mauls, one supplies the pickets, one paces the 3 yards and holds the pickets for driving. Keeping close up so as not to lose the pickets, comes party B with a coil of barbed wire, a pair of wirecutters, and two pairs of hedging gloves. All wire parties carry similar equipment.

Starting at the anchor picket, party B runs out the first straight wire one man holding and uncoiling the wire, the other two taking turns, each taking the turns on alternate pickets.

t 6 yards behind is party C, a picket party which drives the row of pickets, one man again mauling, one holding and pacing, one supplying pickets. This party measures the position of each picket from the front row by going to each picket in the front row, pacing 1½ yards along the line, turning at right angles and pacing 3 yards and then planting the picket. This eliminates cumulative errors.

Starting 6 yards behind C comes party D, which works on the same system as B and puts on the diagonal, keeping behind its own wire.

Party E runs out the first loose wire, starting about 12 yards behind D. One man holds the coil and unwinds it. One man places the wire in position on the diagonal. The third man clips the loose wire to the diagonal.

Party F comes 15 yards behind E and runs out the second straight wire. Party G drives the third row of pickets, measuring the position of each from those of the second row. Party H starts 6 yards behind G and puts on the second diagonal. Party I starts 12 yards behind H and runs the second loose wire. Party K starts 15 yards behind I and completes the bay with the third straight wire.

The direction is kept by the men of the left file, who provide themselves with a piece of string or tape, equal in length to the distance from the parapet to the front edge of the wire. They go out with party A. One man places himself at the foot of the parapet with one end of the string in his hand. The other runs the string out until it is taut. The man on the parapet keeps the string always perpendicular to the general line of the parapet. The other man keeps it taut and moves along with party A. Work can be done with parties of two men, but if one is hit the work is disorganized.

If there are fewer parties the same party may have to do two or more parts of the work. Thus, if there are only six parties A will also do G's work, B will do H's, C will do I's, D will do K's. The pickets must be driven in far enough in the first instance. If they have to be driven after the wire is on, the wire will be too low. Mauls should be muffled with sandbags nailed on.

Advantages of low wire entanglement.—Easily thickened, quick, easy to conceal, not easily destroyed by hostile fire or by friendly fire which will pass over it. The men are always behind the wire. Easy to mend. This entanglement requires 1 picket and 11 yards of barbed wire for each yard of front.

69. **French wire.**—This consists of a continuous spiral of plain wire 3 feet 6 inches in diameter, each turn of wire being clipped to the turns on both sides in five places. When closed up it looks very much like a coil of plain wire, but when pulled out it makes a cylinder of wire mesh. Each small coil pulls out to a length of 20 yards (fig. 87). A big coil consists of five small coils.

The extended coil can be easily crushed down by throwing a weight on the top and must therefore be supported by pickets and barbed wire. It is easily carried and quickly put up. It is held in place by iron staples 5 inches long. The number of men required for a party is 26. Two men keep the direction with a string as for low wire and the remaining 24 are divided into parties of three as for low wire.

Two or more rows of French wire make an obstacle. Each small coil is stapled down in five places; that is, at each end, one-fourth one-half, and three-fourths of the way along. Where two coils meet the same staple fastens down both coils.

Pickets 5 feet long are driven into the center of the coils in five places as for the staples. These pickets should be driven in at least a foot. A strand of barbed wire is run along the top of each row of French wire, being fastened to the pickets with a round turn 6 inches above the French wire. These strands of barbed wire are pulled as taut as possible and are twisted on the French wire with a staple, peg, or pair of wire cutters close to each picket and in several places between the pickets. This barbed wire supports the French wire.

The two rows of French wire are about 2 feet apart and tied together by a diagonal strand of barbed wire running from the tops

Fig. 84

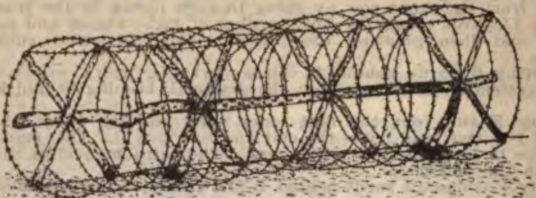


Fig. 85

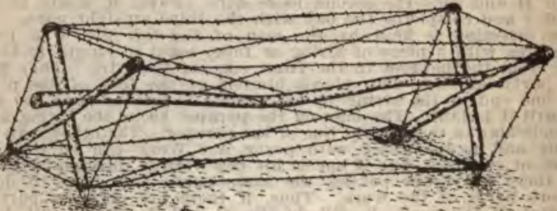


Fig. 86

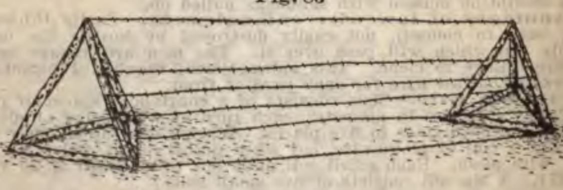
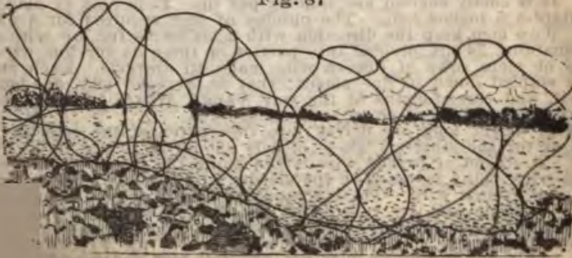


Fig. 87



of the pickets of one row to the tops of the pickets of the other row.

In addition, a strand of barbed wire is run along the front of the front row of French wire and twisted to it. This is partly to hold up people trying to crawl through and partly to hold the French wire together, should it come loose from its fastenings. This wire is usually called the "apron wire." After this, more apron wire can be added or loose wires may be inserted between the two rows.

Duties of wiring party.—Party A, first French wiring party:

A 1 holds end of wire and staples it down.

A 2 pulls wire out for 20 yards.

A 3 shakes wire clear of obstructions and puts in staples one-half and three-fourths way along.

A 1 gets another coil and butts it against A 2's end of the first coil and staples both ends together.

A 2 and A 3 proceed as before and so on until the first row is complete. A 1, 2, and 3 carry 15 to 20 staples slung on a cord over the shoulder. As soon as party A is clear, party B comes out.

B 1 mauls in the anchor picket and the long pickets through the center of the coil every 5 yards along the line.

B 2 measures distance and holds pickets for driving.

B 3 supplies pickets.

B 1 should be a tall man. Where coils butt up against each other they are crossed and the picket is driven through both coils holding them together. As soon as party B is clear party C comes out.

C 1 uncoils barbed wire.

C 2 makes fast end to anchor picket and then takes a round turn with the barbed wire around every picket about 6 inches above the French wire.

C 3 twists the barbed wire to the French wire close to each picket and in three or four places between. He carries pegs or staples for this purpose.

As soon as C is clear party D comes out.

D 1 has a coil of barbed wire and runs it out up against the front of the French wire about halfway up.

D 2 and 3 twist it to the French wire every 2 or 3 yards, thus forming the apron.

Next come parties E, F, and G, who run out a second row of French wire behind the first row at such a distance that a man can just pass between the two rows. Their duties are identical with those of parties A, B, and C.

Next comes party H.

H 1 has a coil of barbed wire and moves between the two rows, uncoiling the barbed wire.

H 2 and 3 move on either side of the entanglement and make this barbed wire fast to the pickets, H 1 holding the coil in such a way as to enable H 2 and 3 to reach it. This forms the diagonal.

70. Where opposing trench lines are very close together, stakes can not be driven for the usual form of wire entanglement on account of the noise of driving, which would draw fire. If not too close to the enemy, iron rods with a screw end may be used in lieu of stakes; these may be three-fourths inch diameter with one or two loops in their length to which to fasten the wire. In ordinary ground such rods can be screwed into a firm hold without noise. When the enemy is too close for this, various forms of portable obstacles in the nature of chevaux de frise are employed (figs. 84 and 85). These are made up at the depots, brought forward through the trenches, and simply tossed out in front, by day or by night.

71. **The high wire entanglement** (fig. 88) is similar in a general way to the low entanglement, but is 4 to 6 feet in height. It usually consists of three to five rows of stakes connected by barbed wire. In addition to the horizontal wires connecting the tops of the stakes, it has diagonal wires running from the top of each stake to the bottoms of all adjacent stakes. The side toward the enemy should

be completed as an ordinary wire fence. Slight irregularities in height of stakes and arrangement of wires add to the value of the obstacle.

72. Openings for the passage of troops through wire entanglements are generally about 10 yards wide and are placed so that two belts of wire overlap the openings. The continuity of the obstacle may be preserved by using gates or barriers that can be quickly opened and closed.

The best place for the openings is at the flanks of the supporting points between the wire entanglements around the supporting points and those in the intervals. If these openings must be placed in the intervals on account of the terrain, they must be covered by the close fire of sections of trench placed immediately in rear.

The **maintenance** of a wire obstacle requires constant care. It should be inspected every night, and a few men should be detailed in each company as a permanent wiring party for the repair and improvement of the obstacle.

73. **Electrified wire.**—In addition to barbed wire, a charged electric wire is at some places maintained, the current being supplied by a gasoline engine and dynamo. The wire is charged in sections so that in a case of a ground only the section affected will be out of service instead of the entire wire.

74. **Abatis** consists of trees lying parallel to each other with the branches pointing in the general direction of approach and interlaced. All leaves and small twigs should be removed and the stiff ends of branches pointed.

Abatis on open ground is most conveniently made of branches about 15 feet long. The branches are staked or tied down and the butts anchored by covering them with earth. Barbed wire may be interlaced among the branches. Successive rows are placed, the branches of one extending over the trunks of the one in front, so as to make the abatis 5 feet high and as wide as desired. It is better to place the abatis in a natural depression or a ditch for concealment and protection from fire. If exposed to artillery, an abatis must be protected either as above or else by raising a glacis in front of it. Figure 90 shows a typical form of abatis. An abatis formed by felling trees toward the enemy, leaving the butt hanging to the stump, the branches prepared as before, is called a **slashing** (fig. 91). It gives too much cover, and should be well flanked.

75. **A palisade** is a man-tight fence of posts. Round poles 4 to 6 inches in diameter at the large end are best. If the sticks run 5 to 8 inches, they may be split. If defended from the rear, palisades give some shelter from fire and the openings should be made as large as possible without letting men through. If defended from the flank, they may be closer, say 3 to 4 inches apart. The top should be pointed. A strand or two of barbed wire run along the top and stapled to each post is a valuable addition.

Palisading is best made up in panels of 6 or 8 feet length, connected by a waling piece, preferably of plank, otherwise of split stuff. If the tops are free, two wales should be used, both underground. If the tops are connected by wires, one will do.

Palisades should be planted to incline slightly to the front. As little earth should be disturbed in digging as possible, and one side of the trench should be kept in the desired plane of the palisade. If stones can be had to fit between the posts and the top of the trench, they will increase the stiffness of the structure and save time in ramming, or a small log may be laid in the trench along the outside of the posts. Figures 92 and 93 show the construction and placing of palisades.

76. **A fraise** is a palisade horizontal, or nearly so, projecting the scarp or counterscarp. A modern and better form consists ports at 3 or 4 foot interval, connected by barbed wire, forming izontal wire fence (fig. 94).

77. **Cheveaux de frise** are obstacles of the form shown in figure 95. They are usually made in sections of manageable length chained together at the ends. They are most useful in closing roads or other narrow passages, as they can be quickly opened for friendly troops. The lances may be of iron instead of wood and rectangular instead of round; the axial beam may be solid or composite. Figures 96 and 97 show methods of constructing cheveaux de frise with dimension stuff.

78. **A formidable obstacle against cavalry** consists of railroad ties planted at intervals of 10 feet with the tops 4½ feet above the ground, and connected by a line of rails spiked securely to each (fig. 98). The rail ends should be connected by fishplates and bolted, with the ends of the bolts riveted down on the ends.

Figures 99 and 100 show forms of heavy obstacles employed in Manchuria by the Russians and Japanese, respectively. The former is composed of timber trestles, made in rear and carried out at night. The latter appears to have been planted in place.

79. **Military pits** or **trous de loup** are excavations in the shape of an inverted cone or pyramid, with a pointed stake in the bottom. They should not be so deep as to afford cover to the skirmisher. Two and one-half feet or less is a suitable depth. Figure 101 shows a plan and section of such pits.

They are usually dug in three or five rows and the earth thrown to the front to form a glacis. The rear row is dug first and then the next in front, and so on, so that no earth is cast over the finished pits.

An excellent arrangement is to dig the pits in a checkerboard plan, leaving alternate squares and placing a stake in each of them to form a wire entanglement (fig. 102). One man can make five pits on a two-hour relief.

80. **Miscellaneous barricades.**—Anything rigid in form and movable may be used to give cover from view and fire and to obstruct the advance of an assailant. Boxes, bales and sacks of goods, furniture, books, etc., have been so used. The principles above stated for other obstacles should be followed, so far as the character of the materials will permit. The rest ingenuity must supply. Such devices are usually called **barricades** and are useful in blocking the streets of towns and cities.

81. **Inundations.**—Backing up the water of a stream so that it overflows a considerable area forms a good obstacle even though of fordable depth. If shallow, the difficulty of fording may be increased by irregular holes or ditches dug before the water comes up or by driving stakes or making entanglements. Fords have frequently been obstructed by ordinary harrows laid on the bottom with the teeth up.

The unusual natural conditions necessary to a successful inundation and the extent and character of the work required to construct the dams make this defense of exceptional use. It may be attempted with advantage when the drainage of a considerable flat area passes through a restricted opening, as a natural gorge, a culvert, or a bridge.

Open cribs filled with stones, or tighter ones filled with gravel or earth (see Bridges), may form the basis of the obstruction to the flow of water. The usual method of tightening cracks or spaces between cribs is by throwing in earth or alternate layers of straw, hay, grass, earth, or sacks of clay. Unless the flow is enough to allow considerable leakage, the operation will not be practicable with field resources. A continuous construction, shown in section in figure 103, is frequently employed. The ends of the dam must be carried well into the earth to prevent the water from cutting around them.

When the local conditions permit water to be run into the ditch of a parapet it should always be done.

82. **Accidental cover** includes accidents of the terrain which can be used to advantage as cover from view and fire. Such are **walls** and other inclosures, **buildings, cuttings, embankments, woods,** etc.

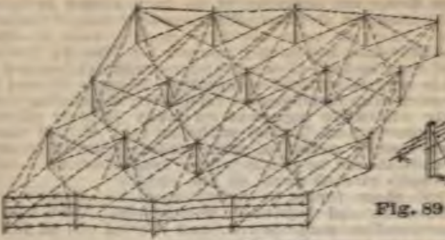


Fig. 88

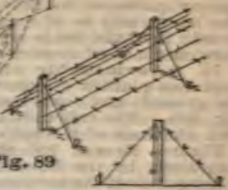


Fig. 89

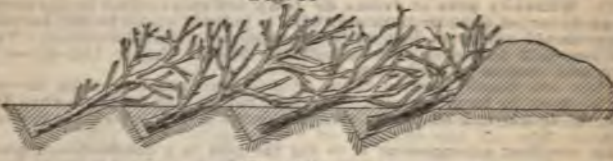


Fig. 90

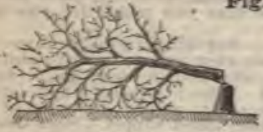


Fig. 91

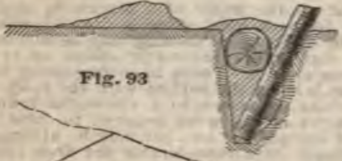


Fig. 93

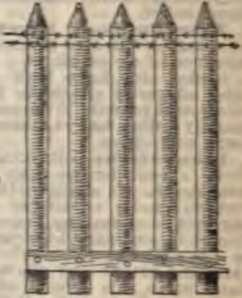


Fig. 92

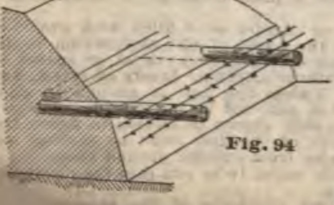


Fig. 94

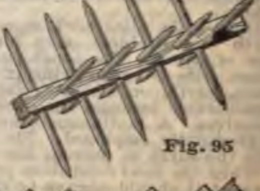
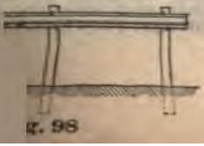


Fig. 95



g. 98

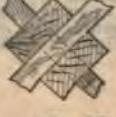


Fig. 97

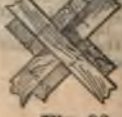


Fig. 96

All these require preparation to better subserve their purpose. The application of the foregoing principles to such conditions is sufficiently indicated by the illustrations. The preparation has mainly to do with the defensive adaptation of the cover by providing for fire from it.

Figure 104 shows the preparation of a wall less than 4 feet high for a single tier of fire. Figure 105, the same for a wall 6 feet high. Figure 106, the same for a wall 7 feet high. Figure 107, a wall 9 feet high for two tiers of fire, one standing and one lying. Figure 108, the same for one tier standing and one kneeling.

Figure 109 shows the treatment of a hedge which screens the parapet from view, holds the exterior slope at a steep pitch, and forms an excellent head cover.

Figure 110 shows the best method of preparing a low embankment and figure 111 a high one.

Figure 112 shows three methods of treating a railroad cut; one by a tier of fire on the lower side, another by a tier of fire on the upper side, and the third by a firing crest on the track. Retreat from the first and advance from the second are obstructed by the cut itself. Both may be used, the fire of the rear line covering the retreat of the front one. Care must be taken that the rear line can not shoot into the forward one.

83. **Buildings** if exposed to artillery are untenable, but against rifle fire are made defensible by barricading all windows and doors, except one for ingress and egress on the most sheltered side, and providing loopholes.

Barricades for doors and windows may be of solid materials, such as timber, iron, brick, stone, of stockade construction, or of hollow articles of any kind which will form receptacles to retain earth or other bullet-proof filling. Articles of furniture, trunks, baskets, and barrels may be mentioned. (See also Revetments.) Bags are useful here as everywhere.

A house of stone or brick will give some protection from fire. A wooden house gives protection from view only, unless time suffices to stockade the walls. Care must be taken not to exclude too much light. Openings in partitions should be enlarged and additional ones made to give the freest possible communication. Hatches should be cut through the floors and roof to give free escape of smoke and gases.

Loopholing is done as already explained. The loopholes should not, as a rule, be less than 4 feet apart in the same tier. They should be arranged to concentrate fire in front of doors or accessible windows. Doors should be further strengthened by barricades across the spaces into which they open.

If bay windows or other projections are available, they may be utilized for **flanking fire.** The loopholes for them may well be near the ground so that a tier for other fire can be placed above them.

As soon as the barricades and necessary banquettes are finished all other combustible material should be removed and a supply of earth and water for fire fighting should be placed at convenient points. **Stores** and **ammunition** are also brought in and disposed of in suitable places. A space as secure as possible from fire should be set apart and prepared as a **hospital;** and **latrines** must also be arranged for.

The defensive preparation will depend much on whether the house is to stand an actual assault, or only to afford an advantageous cover for fire upon the enemy while approaching. This should be determined and announced when the order to occupy the house is given. If the building is to be held to the last, a good flank defense must be arranged and the interior walls must be loopholed and arrangements made to quickly barricade interior openings, so that a fighting retreat may be made from room to room.

In addition to tambours and caponieres, flanking by vertical fire may be accomplished, as shown in figure 113. Such a construction is called a **machicoulis gallery.** Fire from such a gallery is not very effective and will usually not be worth the trouble of preparing

Fig. 99

Fig. 100

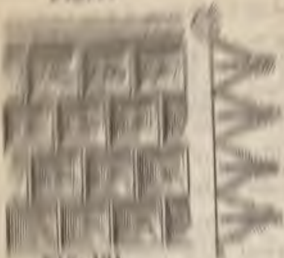


Fig. 101

Fig. 102

Fig. 103

Fig. 104

Fig. 105

[illegible]

[illegible]

for it. Hand grenades, small enough to be pushed through the loopholes, will be equally effective.

84. While the defensive preparation of the building is in progress the adjacent **ground must be cleared** of all obstructions to fire and such obstacles as are possible constructed. **Good obstacles** make flank defense much less necessary, except for houses to be held as long as possible regardless of losses.

85. **Villages.**—Villages of well-built houses can often be turned to excellent advantage for defensive purposes, and the issue of many important battles has depended on their capture. The outer buildings and inclosure walls facing the attack not only afford a strong firing line, but the interior and rear of the village furnish good cover for supports and reserves. An obstinate step-by-step defense can be arranged by the use of interior buildings and street barricades.

In preparing a village for defense, the strong main line should be provided along the outer edge by putting walls of buildings and inclosures in a defensible condition. If the village is subjected to artillery fire, the main line of defense should be placed in fire trenches a short distance in front of the outer line of the village with ample covered communications leading to the rear. The front lines should be divided into definite sectors of defense to which complete units, companies or battalions, are assigned. Interior lines of defense may be prepared along streets parallel to the front, and a final stand made in any strong central building in an open space, such as a church or courthouse. Machine guns can be used effectively from behind barricades sweeping the streets leading to the front. Good communications are an important feature in the defense of a village, and these should receive especial care, the necessary openings through walls being provided for this purpose. Artillery for the defense of villages should be placed outside and to the rear of the flanks.

86. **Woods.**—Woods offer less advantages for defensive purposes than villages. Since the front edge of a woods often makes a good target for the enemy's artillery, it will generally be best to place the fire line in rifle trenches a short distance in advance of the edge and to use the woods as cover for supports and reserves. If the edge of the woods is ragged and the woods not too dense, a trench may be placed just inside the edge, where it will be concealed from view. Digging inside woods is difficult on account of roots, but frequently sufficient dead branches, logs, etc., can be heaped up and covered lightly with earth from a shallow trench to give a good parapet. Shell fire on woods, although not materially destructive, is apt to be demoralizing to men's nerves. Woods afford the material for abatis, and this should be freely used, especially along reentrant portions of the edge when it can be flanked from the salient parts. As in the case of villages, ample communications are essential for a successful defense. These should be marked by signposts and lanterns to show plainly the positions to which they lead. If time permits, a clearing may be made through the woods and its rear edge occupied as a second line of defense. Usually this is impracticable on account of the enormous labor involved, and but a single line of defense along the outer edge can be provided.

87. **General considerations.**—The foregoing paragraphs involve the general supposition that the best is attainable. In actual service this will not often be the case. War does not usually permit sandpapering and polishing. The main thing is to get some substantial result and get it quickly. The military engineer, considering projects for field fortifications, must reckon with four imperative limitations—lack of time, lack of men, lack of tools, and lack of materials. Each of these tends to defeat his object of doing the very best thing and compels him to work out a scheme which goes as far in that direction as his limitations permit. The best is to be kept in view always to steady the aim even if it can not be reached.

The first move should be to take account of stock by finding out what time is allowed, what force is available, what tools are on hand, and what materials can be procured. The relative quantities and numbers hereinbefore given are to be considered as minima. Every effort should be made to get at least that number, and by all means get more if possible, especially of men. The more men the easier the work of each and the better condition all will be in when the work is finished. Manual labor for soldiers in the field is a necessary evil at best and should always be minimized.

Knowing from the time, force, tools, and materials to be had what can be done in the aggregate, lay out a scheme within the limits, following such of the preceding principles as are fundamental and slighting as much as may be necessary those which are secondary only. An incomplete or emergency scheme leaves some risk uncovered. Decide which is the least probable risk and economize time and labor in that direction.

88. **Latrine** accommodation should be ample: seats should be based on at least 2 per cent of the troops using them. Urine receptacles should be based on the same scale. Latrines should be provided for all trenches and shelters which have to be occupied even for short periods by troops.

89. The following are some of the various kinds:

Box latrine.—This consists of a pit 15 feet long by 2 feet wide by 6 feet deep. A square box or boxes are placed on top. The sides should be boarded all round so that the boards project over the sides of the pit. The height of the box should be 17 inches. Two holes are made in it and lids provided. If deep enough it does not smell. It is most suitable for trenches, provided the ground is dry.

If there are frequent approach trenches, say one every 100 yards, a good position is just off the approach trench. This may not be suitable, depending on the trench; in some cases a suitable site is at the corner of a traverse.

Bucket system.—If the ground is wet and deep trenches can not be dug the bucket system is most suitable for trenches. Any metal receptacle will act as a bucket. The excreta must be covered with earth. It is very important that every officer, noncommissioned officer, and man shall make it a habit to cover the excreta every time before he leaves the latrine. Officers and men are apt to forget this and in five minutes the excreta will be covered with flies. The buckets are removed and emptied at night.

The short-trench system is suitable only on the line of march when a halt is made for a night or two. These should be dug 3 feet long by 2 feet wide by 1 foot deep with 4 feet 6 inches interval between latrines, so that when the first lot are full and covered in fresh ones can be dug between, leaving a margin of 9 inches on each side of the hole of solid and not foul ground.

90. Every latrine should have a separate pit dug for a **urinal.** The following are the various kinds:

Pit with tin can on top.—The purpose will be served by any pit 3 feet deep and 3 feet in diameter, with stones in the bottom, covered over with a tin can perforated at its bottom placed on the stones.

Trough system.—This is more elaborate and suitable for a permanent camp. A trough slightly inclined, 2 feet long, made of wood lined with zinc. Oil can at one end out on the ground, placed to catch flow from the trough.

Pipe system.—This consists simply of an oil can with a pipe soldered on, conducting the flow to a pit 3 feet deep. This is clean and simple.

In trenches it is sometimes impossible to dig a pit, and an ordinary oil can placed in a suitable position as container can be used.

91. **Disinfectants.**—Bleaching powder (chloride of lime) should be freely used at every latrine and urinal. All ground which has been used for latrines should always be marked "foul ground."

92. **Drainage** is essential to the preservation of trenches and the health and comfort of the troops. In deliberate works it is well to study the drainage question in detail and to dig special ditches of ample capacity before work on the trenches proper is begun. Of course, this can not be done in the presence of the enemy. About the only remedy in that case is the construction of floors or gratings, the collection of water into pits, and its removal by constant pumping. The bottom of the trench should slope toward the back, where the water may be run to a pit in a drain. Where the soil is impermeable an endeavor should be made to reach a permeable layer by boring with an earth auger. In hilly terrain the water may be drained off by pipes placed under the parapet. If a permeable layer can not be reached, the drainage pits must be emptied with buckets or pumps.

The drainage and flooring of **approach and communicating trenches** in constant use is specially important, and should be considered in selecting their location. When timber for flooring is not available, drains filled with broken stone should be constructed in the bottom of the trench. A good form of floor grating is made of cross pieces of ¾ by 4 by 24 inch boards nailed to two longitudinal pieces of timber about 3 by 4 inches by 6 feet set on edge.

In **shelters,** provision should be made for the drainage of water which runs through the entrance or seeps through the walls. A drainage pit should be constructed near the entrance and the floor of the shelter should be sloped toward it; the pit must be emptied when necessary. The roofs of shelters should be made waterproof by using roofing paper, corrugated iron, tin or zinc, linoleum, canvas, or tiles.

TRAINING IN FIELD FORTIFICATION.

93. Infantry must be capable of the construction, repair, and maintenance of all forms of trenches, shelters, and barbed-wire entanglements. Constant practice in digging and making entanglements at night is necessary. Officers and men must be well trained in the method of marking out works to be dug at night and in extending a party silently on a task in darkness. Troops should be trained to dig fully equipped except for their packs. It will be useful to have a certain number of men in each company specially trained, under engineer supervision in the construction of obstacles, loopholes, revetments, and drains.

The output of work is much greater when the workers have been systematically trained and when they are correctly distributed to their several tasks and directed by competent noncommissioned officers.

94. The **elementary training** need take only two or three weeks, but what is learned should be learned with great thoroughness, so that each man in actual operations will know exactly what he has to do and what to expect of his neighbors. This instruction can be given from this Manual, and should include the use of the different tools listed in the Unit Equipment Manual, the most effective way of handling them, systematic distribution of tools and tasks, coöperation so that men will not get in each other's way, and knowledge of the adopted sections and types of construction.

The types of construction are few in number, and the men should be trained to build without hesitation the normal or usual type of firing trench, communicating trench, machine-gun emplacement, covered shelter, cave shelter, and to break out and work a sap. Special constructions beyond the above list can be given later to those best qualified to receive it, or in cases of special emergency.

Instruction of troops should prepare them to take their places immediately among the combatants when they go to the front as reinforcements. For their own sake they must know all the latest methods of combat, both defense and attack.

It has been noted that in training the reserves and troops in depots in some of the European armies not enough attention is given to grenade instruction, sapping, rules for life in cantonments, duties in the trenches, actual assaults, and combats in a labyrinth of communicating trenches and barricades.

95. All **depots** should have on hand a sufficient number of tools, sandbags, and unloaded but primed grenades, without which training for trench work is purposeless and futile. Combats with blank cartridges should be carried out daily in lines of entrenchments copied after those of some known and tested field of battle. The men in reserve need instruction for the work they will take up at the front and should have full course in work, discipline, and life in the trenches.

ORGANIZATION OF A DEFENSIVE POSITION.

96. **A defensive position** may be occupied as a result of an indecisive combat in which certain positions are seized, or as a result of previous selection of a suitable terrain. If time is available for a previous selection, the most suitable points may be selected. If the position is taken up as a result of an indecisive combat, the positions occupied are not necessarily good, and a consolidation and readjustment of the line is promptly undertaken utilizing the positions occupied, as far as they are suitable. This general line is often made more satisfactory by capture, through concentrated effort, of certain positions in the hands of the enemy and less often by withdrawal of troops from exposed positions already occupied and intrenched by them.

Whatever may be the manner of occupation, a **defensive position, completely organized for defense,** consists in its simplest form of the following:

(*a*) **Foreground** cleared and obstructed by obstacles.

(*b*) **Firing trenches,** consisting of a line of **strong points,** which may or may not be connected by trenches in the intervals. Many machine guns are generally included in the firing trenches.

(*c*) **Support trenches,** connected with the firing trenches by **approach trenches.** As a rule a battalion is assigned a sector for defense, and it furnishes its own supports. Certain sections of firing trenches and support trenches, with approach trenches, are called **supporting points.** (See figs. 118 and 119.)

(*d*) **Command posts,** intrenched in most suitable positions.

(*e*) **Reserve** and **approach trenches.**

(*f*) Artillery positions, staff positions, more reserves, etc.

97. A **general line** to be occupied by previous selection can usually be selected from the map in such manner as to meet the strategical and tactical requirements of the situation. The entire front is divided into sectors or sections, assigned to brigades, regiments, and battalions. This simplifies command and insures continuity of the defense. If the map is a good one (such as the maps of the U. S. Geological Survey), the brigade sectors may be selected therefrom, but for the assignment of the smaller sectors and the organization of supporting points an examination of the ground is absolutely essential. Any attempt to make such assignments from the map alone would be very apt to result diastrously.

The matters to be considered in organizing a defensive position are: The mission of the command, numbers and quality of troops, strength, position, and probable intentions of the enemy or of any supporting troops in the vicinity, the nature of the terrain, the weapons of both combatants, the efficiency of fire, artillery positions available for both sides, ease of support, maneuver, or retreat, reinforcements expected, whether delaying or decisive action is contemplated, time the position must be held, time available for preparation, etc.

98. **Supporting points** are the unit areas of the defensive position. They may consist of a single knoll, a single nose convex toward the enemy, a piece of wooded ground, a small village suitable for defense by a small combat unit, a large woods, a group of hills

or noses, a large town suitable for defense by a large combat unit, etc.

The combat unit assigned for the defense of any supporting point will vary with the size and importance of the area to be defended, its relation to the rest of the line, the difficulty of organization, proximity to a threatened flank of the general line, distance from active supporting troops, etc. In our organization a battalion is the smallest unit which ordinarily holds a support, and it is the smallest unit usually assigned to the occupation of a supporting point.

In field fortifications closed works find little application. The front is covered by a wide extent of rifle trenches, so disposed as to fire on all portions of the terrain over which an advance of the enemy is practicable. There should be a maximum development of frontal fire and arrangements for mutual support by means of cross fire.

The general location of the line and the area assigned to the unit will fix approximately the position to be occupied. It must, of course, be within the sector, but some leeway in the direction of depth is allowed so long as the unit does not unduly expose its own flank or those of the adjacent supporting points on either side, which are (in a measure) dependent upon it for fire support.

It will thus be apparent that a unit may often be forced to organize a supporting point in a locality which at first glance appears to offer a very poor field of fire.

99. **Siting of trenches.**—There are many conflicting considerations to be taken into account in deciding on the best siting for trenches. Reports have been received of the placing of trenches on the reverse slopes of hills in order to protect them as far as possible from artillery fire, and statements have been made that 100 yards in front is sufficient field of fire, since obstacles, rifle, machine-gun, and artillery fire can check an enemy in that distance. Reverse slope positions have been advocated by a few authorities for some years. They tend to confine their occupants to the defensive, permit the enemy to approach the covering crest with little loss, and afford but a restricted field of fire. The statement, "The siting of trenches so that they are not under artillery observation is of prime importance, and an extensive field of fire is a secondary consideration," should be accepted with some hesitation, because the moment a restricted field permits an enemy to approach within one or two hundred yards that position is no longer concealed. Experience has shown that sensible losses from infantry fire are incurred at distances as great as 2,000 yards, and that at 1,000 yards this fire may attain tremendous power. The choice between a site in front and one in rear of a crest is influenced by local conditions governing the effectiveness of our own and the enemy's fire and upon the relations obtainable among the various elements of the defense. In general the best location for effective fire trenches lies between the military crest of rising ground and the lowest line from which the foreground is visible. If the position at the crest is conspicuous, it is inadvisable. Positions forward of the crest sacrifice command and limit distant view, but are less exposed to hostile fire. The chief disadvantage of a position forward of the crest is the difficulty of communication and withdrawal. The location of rifle trenches is to-day, just as much as ever, a matter of compromise to be determined by sound judgment on the part of the responsible officers.

100. **General description of an intrenched zone.**—The "first intrenched zone" includes the foremost firing trenches and the cover, support, intermediate, and reserve trenches. An obstacle, continuous except for narrow passages for patrols, is in front of the firing, support, intermediate, and reserve trenches and between strong and supporting points and approaches. (See figs. 1 and 2.)

The front line consists usually of two parts, the firing trench and the cover and communicating trench.

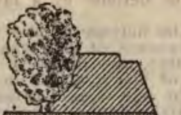


Fig. 109

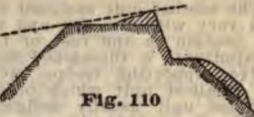


Fig. 110

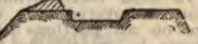


Fig. 111

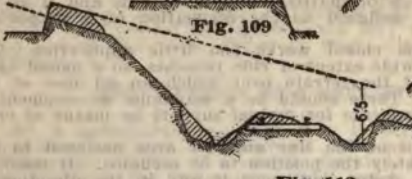


Fig. 112

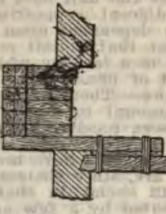


Fig. 113

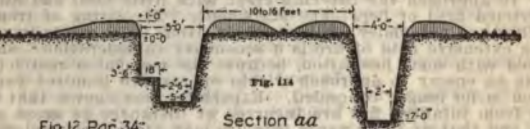
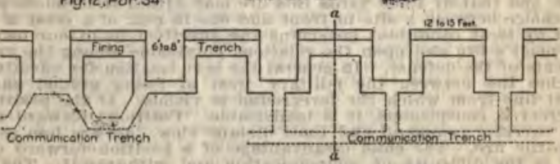


Fig. 114



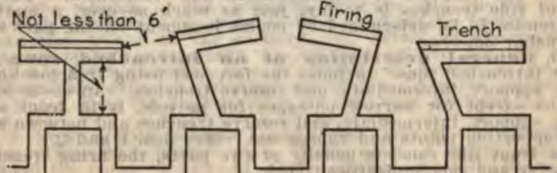


Fig. 115

FIRST LINE FIRING TRENCH

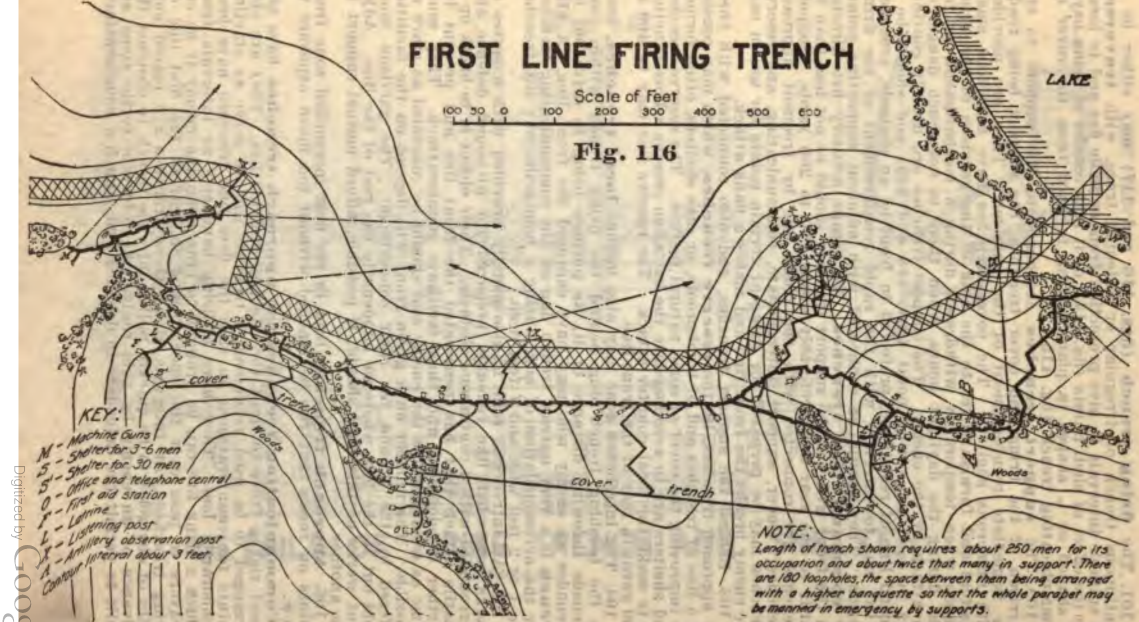


Fig. 116

NOTE:
Length of trench shown requires about 250 men for its occupation and about twice that many in support. There are 180 loopholes, the space between them being arranged with a higher banquette so that the whole parapet may be manned in emergency by supports.

101. The **firing trench** (figs. 116 and 117) may either be a continuous trench of irregular or indented trace, with **traverses** at suitable intervals to give protection from enfilade fire and to localize the effect of shell bursts (fig. 114), or it may consist of firing bays, T shaped or L shaped in plan, jutting forward from the cover or communicating trench (fig. 115).

102. The **support trenches** accommodate the support to the garrison of the firing and cover trenches, the support being ready for immediate reenforcement of the garrison. They are provided with numerous shelters. The cover trenches have numerous small shelters and furnish cover to the bulk of the garrison of the firing trench when temporarily withdrawn during a bombardment, or for rest during the daylight hours, when there is not much danger of an attack by the enemy. The support trenches are usually continuous in each supporting point (figs. 118 and 119) and should be a second line of resistance, protected in front by an obstacle, arranged so as not to interfere with the rapid reenforcement of the firing trench. They should be connected with adjacent supporting points by **communicating trenches.** To escape artillery fire directed on the front trenches the support trenches should be not less than 50 yards to the rear and preferably about 100 to 200 yards. Support trenches are connected with the front line by frequent approach trenches. Cover, support, intermediate, communicating, and reserve trenches may be prepared for firing at certain points for use in case the enemy breaks the front line and makes a flank attack.

103. Behind the support trenches, and also connected with them by approach trenches, lie the **reserve trenches,** which may consist of a line of trenches and of bombproofs, or cave shelters, often formed by improving the cover of some natural feature. The reserve trenches and shelters are to accommodate the battalion reserve whose function is to make the local counter attack. The reserve line may be 400 to 600 yards in rear of the front line.

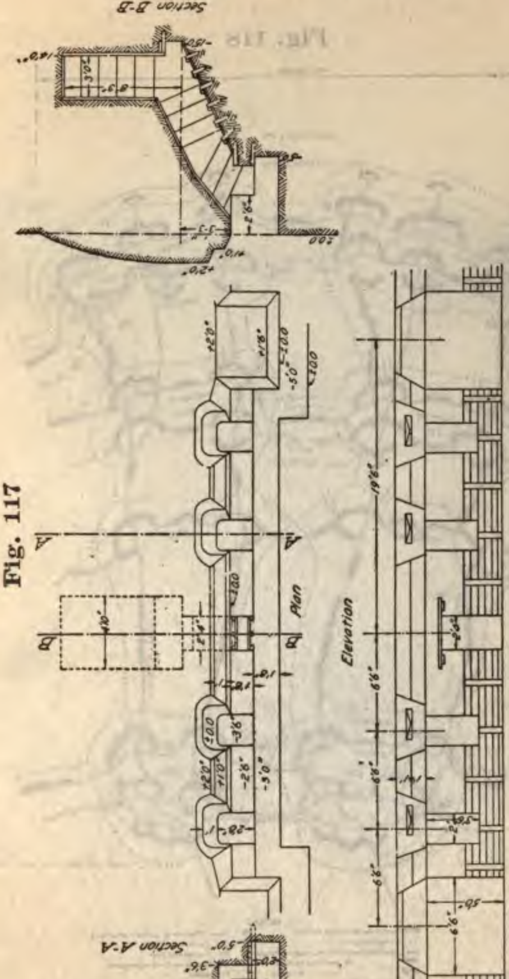
104. The intrenched zone may also include **local trenches,** such as the bombing trench dug behind the firing trench within easy grenade throwing distance of it, its purpose being to drive out by grenades an enemy who may have captured the front line. A **slit trench** is a very narrow trench dug off the communicating trenches for the accommodation of men during a bombardment; slit trenches are 1 or 2 feet wide and 7 feet deep.

105. An intrenched zone is also usually provided with a series of works somewhat like redoubts prepared for all-round defense and surrounded with a continuous obstacle. Their object is to break up a hostile attack that has penetrated the front line and prevent its further development and thus facilitate counterattack. They must come as a surprise to the enemy and should be concealed as much as possible. The number on a given front will depend on the facilities afforded by the ground for their concealment. The garrison must hold out to the last whatever happens to the rest of the line. Adjacent works of this kind should, if possible, afford mutual support to one another.

106. **Approach trenches** lead to the first intrenched zone from [illegible] roads that can be reached without too much exposure to

renches and **approach trenches** have the
imit the effect of enfilade fire. They are also
s defensive trenches and to serve as starting
cks in case the first line trenches have been
y have a firing banquette at intervals from
be brought to bear upon the enemy if he en-
he open ground in rear of the first line of
ervals along these trenches are placed sup-
ickly pulled into the trench to obstruct the
this route. At intervals sortie steps are
ers to debouch and launch a counterattack.

Fig. 117



DETAILS OF FIRING TRENCH AND SHELTER

Section A-B

Fig. 118

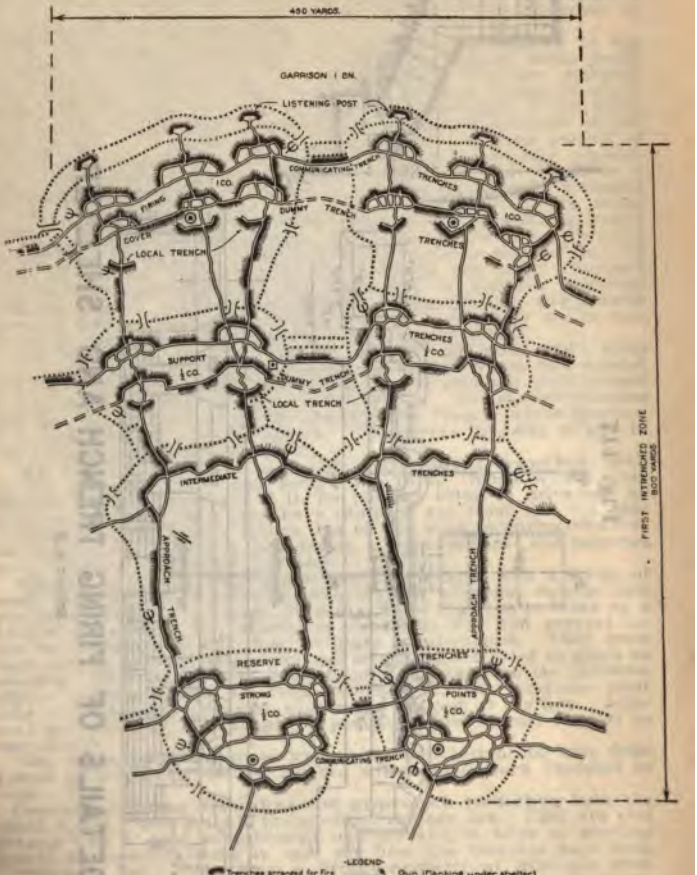
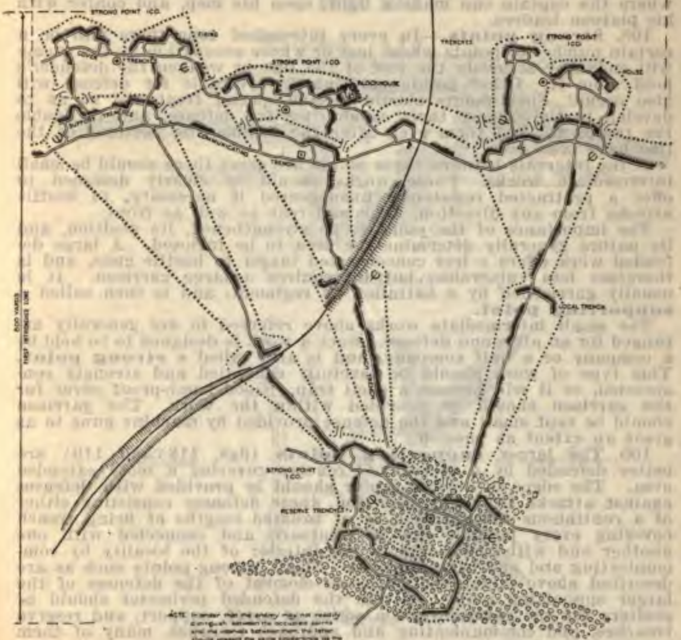

450 YARDS.
GARRISON 1 BN.
LISTENING POST
COMMUNICATING TRENCH
TRENCHES
1 CO.
FIRING
COVER
DUMMY TRENCH
TRENCHES
1 CO.
LOCAL TRENCH
TRENCHES
½ CO.
SUPPORT
½ CO.
DUMMY TRENCH
LOCAL TRENCH
INTERMEDIATE
TRENCHES
APPROACH TRENCH
APPROACH TRENCH
RESERVE
TRENCHES
STRONG
½ CO.
POINTS
½ CO.
COMMUNICATING TRENCH
FIRST INTRENCHED ZONE
800 YARDS
-LEGEND-
Trenches arranged for Fire
Dummy Trenches
Approaches & Communicating Trenches
" with one Firing Parapet
" two " Parapets
Machine Gun
Gun (Flanking under shelter)
Co. Command Post
Bn. Command Post
Barbed wire Entanglement
Passages
Listening Post

Fig. 119


STRONG POINT 1 CO.
TRENCH
STRONG POINT 1 CO.
BLOCKHOUSE
TRENCHES
STRONG POINT 1 CO.
HOUSE
SUPPORT TRENCHES
COMMUNICATING TRENCH
LOCAL TRENCH
STRONG POINT 1 CO.
RESERVE TRENCHES
600 YARDS
NOTE: In order that the enemy may not readily distinguish between the occupied points and the intervals between them, the latter should present the same appearance as the adjacent points.
This is accomplished by digging dummy trenches or communicating trenches in the intervals.
LEGEND
Trenches arranged for firing
Approaches and Communicating Trenches
Machine Gun
Barbed Wire Entanglement
Passages
Co. Command Post
Bn.

A further defensive feature is the occasional elevated platform across the trench at an angle, where one or two men with hand grenades can conveniently oppose an advance along the trench.

Latrines are provided in all trenches and must be in positions easy of access and protected from fire. They are usually made in T heads at the ends of short trenches leading off from the approach, communicating, cover, or support trench.

107. **Assembly points** are former firing trenches which have been organized for a stay of several days, or they are short trench elements dug especially to hold companies during short stays, and in which the men can only sit down. Even the latter should contain water barrels and latrines, also a command post sheltered from rain where the captain can make a light, open his map, and confer with his platoon leaders.

108. **Strong points.**—In every intrenched zone there will be a certain number of points whose loss or whose occupation by the enemy will endanger seriously the rest of the line or weaken the defender's hold upon it. Other points particularly favorable for defense will also occur. Such points should receive special treatment so as to develop to the utmost their capabilities for defense, and to enable the troops to hold them even after the neighboring portions of the line have been lost.

If the intervals between these points are great there should be small intermediate works. These works should be clearly designed to offer a protracted resistance, unsupported if necessary, to hostile attacks from any direction, flank and rear as well as front.

The importance of the point to be strengthened, its position, and its nature generally determine the area to be inclosed. A large defended work offers a less concentrated target to hostile guns, and is therefore less vulnerable, but it requires a large garrison. It is usually garrisoned by a battalion or regiment, and is then called a **supporting point.**

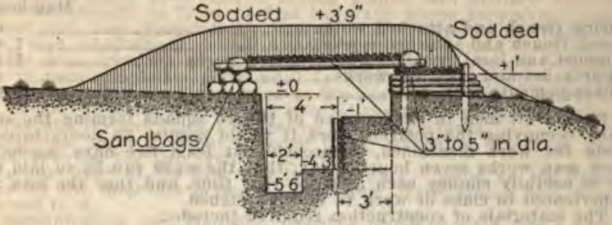
The small intermediate works above referred to are generally arranged for an all-round defense. Such a work is designed to be held by a company or a half company, and is also called a **strong point.** This type of work should be carefully concealed and strongly constructed, or it will become a shell trap. Good bomb-proof cover for the garrison should be provided within the work. The garrison should be kept small and the defense provided by machine guns to as great an extent as possible.

109. The larger **supporting points** (figs. 118 and 119) are better defended by a system of trenches covering a more extended area. The edges of such a center should be provided with defenses against attacks from any direction, these defenses consisting either of a continuous firing trench or of isolated lengths of firing trench covering every possible line of approach and connected with one another and with the works in the interior of the locality by communicating and approach trenches. Small, strong points such as are described above might well form an element of the defenses of the larger supporting point. Within the defended perimeter should be shelters for the garrison and a series of cover, support, and reserve trenches, and communicating and approach trenches, many of them prepared for firing.

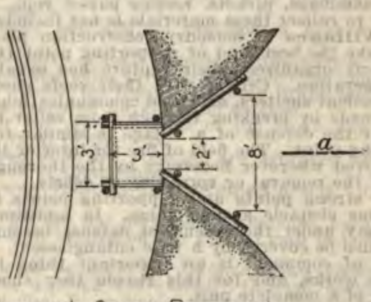
In this way the interior is cut up into compartments, and the scheme of defense is so organized that even if the enemy succeeds in establishing himself at some point in the perimeter, an unbroken front can still be presented to him and the defender's hold on the locality is practically undisturbed.

110. **Machine guns** play an important part in the defense, and
native emplacements should be numerous. The siting of the
cements (fig. 120) should be very carefully considered so as to
rse the guns laterally and in depth, and will largely govern the
al design of the defenses. A supporting point should not offer
centrated artillery target, and its reduction by bombardment

Fig. 120



Section *aa*



Plan with Cover Removed

should be a difficult and lengthy operation, entailing a vast expenditure of ammunition.

111. It will be noted that figure 117 is a diagram of part of a supporting point. Reserve trenches and approaches thereto are not indicated. Based on the assumptions that wire entanglements are 21 feet wide; that firing trenches are constructed in squad lengths of 18 feet with 6-foot traverses between adjacent squad trenches; that a half company contains eight squads, a half company being in each of firing and support trenches; and that the support trenches are 60 yards in rear of the firing trenches, it has been calculated that it would require 4,450 man-hours of work to build the part of the supporting point as represented on Plate III, exclusive of revetment, divided approximately as follows:

	Man-hours.
Firing trench and attached works	650
Cover trench and attached works	1, 050
Support and local trenches and attached works	1, 100
Approaches and attached works	450
Entanglements	1, 200

Should all men in every squad of the 16 squads forming the company occupying the position work it would require 35 hours to complete the work mentioned, or probably at least five days, assuming each man works seven hours a day, that the work can be so laid out as to usefully employ each man for that time, and that the men are experienced in class of work to which assigned.

The materials of construction required include:

Approximately 36,000 board feet of lumber,
Approximately 20,000 linear feet of round timber,
Approximately 110,000 feet of wire,

besides sandbags, pickets, roofing paper, rope, nails, etc. The labor required to collect these materials is not included above.

112. **Villages** of masonry construction placed in a state of defense make the best kind of supporting point (fig. 2). If the defense is properly organized, their capture has usually proved a long and costly operation. Cellars with their roofs shored up and reinforced form excellent shelters, and good communications entirely underground can be made by breaking through from cellar to cellar. The organization of the defense of a village is similar to that described for a supporting point. The field of fire for interior lines of resistance must be improved wherever necessary by the thorough demolition of buildings and the removal or spreading of débris.

These strong points and supporting points should always have a continuous obstacle around them. In addition, any interior trench which may under the scheme of defense become a line of resistance should also be covered by a wire entanglement.

Unity of command is an important thing in the defense of one of these works, and for this reason they should be designed for a garrison of a complete unit.

113. The supporting points must be within supporting distance of each other; that is, effective infantry fire must be able to reach the middle of the interval between adjacent centers of resistance. The intervals are closed by dummy trenches so as to deceive both the aerial observers and the assaulting troops of the enemy. The attacking force will ultimately push into the intervals and may surround the supporting points, but it is necessary to capture the latter before the attack can pass on. It is stated that the power of the defense, under present conditions, does not consist in holding the firing trenches or even the support trenches, but lies in the ability to organize and launch the counterattack. The attack and capture of the firing trenches is not so difficult with efficient artillery preparation, but the holding of captured trenches against a powerful counterattack from the line enches next farther back is the key of success.

The commanders of sectors do not count on holding their firing trenches in case of violent attack, but always have arrangements made in every detail for a counterattack. If the counterattack fails, the final resistance is made in the strong points that form the reserve trenches of the supporting point. Supporting points have been usually the cause of failure of attacks on intrenched lines in the present war. They are considered absolutely essential.

114. In the sketches illustrating supporting points the features to be especially noted are:

Two companies in the firing line, one in support, and one in reserve. Double line of trenches in front line; double line of trenches in support; communicating and cover trenches behind the firing trenches of first line, support lines, and in strong points, two distinct lines of wire entanglement in front of first line; the whole supporting point divided into two longitudinal sections, each protected in flank by wire; each longitudinal section divided transversely into three parts, viz. the firing trenches, the support trenches, and the reserve trenches, each in turn completely surrounded by wire and each protected with trenches arranged for firing faced to the rear as well as to the front and flanks; passages through the wire of the first line made continuous through the two lines, but always in the reentrants.

Listening posts in front of each firing trench of the first line, placed between the two systems of wire.

Machine guns of the first line in reentrants. Those on the flanks to sweep the intervals between this center of resistance and those adjacent to it.

Communicating and approach trenches provided with firing parapets, mostly facing outward toward the wire of each section of the supporting point.

115. Three companies in the firing line, each with one-half in support; one company in reserve.

Wire surrounds at least two distinct portions of each company front.

Wire protects the two flanks of each communicating trench.

Wire divides the supporting point into three distinct portions.

Passages through the wire in the front line are all in the reentrants.

The suporting point is prepared for all-round defense.

The emplacements for the machine guns of the front line are in reentrants to sweep the front of the wire.

The communicating and approach trenches are arranged for firing throughout a large portion of their length.

Communicating and cover trenches extend behind nearly all of the firing trenches.

The railroad cut and fill are not prepared for defense, because for one reason they are too well located on the general map in possession of the enemy.

115½. Arrangements must be made for reconnaissance parties and for attacking columns to debouch conveniently through openings in the line of defense protected by movable obstacles. These openings must be under the fire of the support trenches.

Support trenches are from 100 to 200 yards in rear of the front-line defenses. They are not continuous as a rule. Their purpose is to limit the retreat of a fraction which may have been thrust back temporarily from the front line and to give time for the reserves to arrive and counterattack.

116. Farther to the rear is a line of strong points garrisoned by local reserves supporting the firing trenches and the support trenches, and sweeping with its fire all the ground in rear of the forward lines. These strong points are less numerous and less developed than those forward and are surrounded by obstacles. The intervals between strong points are filled with obstacles arranged to allow passages for the debouching of troops in reserve when used in counter attacks; these counter attacks may be made by the garrison of the reserve trenches of a battalion supporting point or by the regimental

reserves; the passages are properly covered by fire. About half the crests are furnished with loopholes, and the other half with uncovered parapets, which permit, at the moment of assault, the most rapid fire. Machine guns and light artillery may also be used advantageously when available. It is important to direct the axis of the loopholes so that there is no danger of firing into the adjacent supporting or strong points.

The reason for breaking a front or indenting a line to provide flanking fire, is that a rifleman fires ordinarily at right angles to the crest of his trench or not more than 30° on each side of such direction. Do not count too much on oblique fire, especially to the right oblique, as the latter requires a displacement of the usual position of the soldier.

117. **Intrenched zones in rear of the first zone.**—These may consist of an intrenched zone 2 to 3 miles in rear of the first zone, usually behind a protecting ridge or crest, and connected with the first zone by artificial or natural communications that furnish fairly good concealment from the enemy's view and artillery. **A more elaborate defense** may cover a zone in rear 4 to 5 miles deep, in which every point of tactical importance is fortified by supporting points as already described. Troops occupying these points can break up the attack of a hostile force that may have penetrated the front system, delay the further advance, and facilitate counterattack. They also furnish a framework on which, by digging trenches connecting the supporting points, a new line can be quickly constructed to hold against vigorous attack.

One or more similar zones may be constructed farther to the rear.

118. **Flanks.**—If the flanks of an intrenched position do not rest on impassable obstacles they may be turned by an active enemy, unless special defensive arrangements are made. The best method is to refuse the flanks gradually by trenches in echelon until some supporting point is reached. The flanking trenches should not be turned obliquely to the main front, as this exposes them to enfilade and does not seriously increase the circuit of a turning movement.

119. **Trace.**—A common tendency is to make the trace too straight. An irregular line with frequent salients and reentrants gives greater facilities for concentration of fire over any desired area and for the most effective employment of machine guns. Such a trace will expose short lengths of trench to enfilade fire, but the effect can be reduced by proper traverses. The enemy's line will also be in salients and reentrants and will be equally exposed to enfilade from our side.

Minor irregularity of trace is essential and should always be obtained. The creation of large salients to include an important tactical point will depend upon the following important conditions:

(*a*) Whether the possession of the point in question by us will facilitate future offensive action without unduly weakening our line.

(*b*) Whether its possession by the enemy will seriously threaten the security of our trenches.

The permissible traces for communicating and approach trenches are the indented line, easy to dispute in case of attack, and the zigzag, which gives better defilade. The litters evacuating wounded move more readily in the latter trace.

The best type is the winding one, but the curves must be suffi-
ntly pronounced to give real protection against enfilade fire. If
erses are used in communicating and approach trenches the best
s the island traverse with the trench going round it on both

ncealment.—Aerial reconnaissance makes concealment of
mpossible, but isolated works and gun emplacements can
trenches in woods may escape observation if clearing
. Airplane photographs show clearly every trench
open country, and even wire entanglements. Never-
ort should be made to make the work inconspicuous,
servers by dummy trenches, to avoid paths or tracks

that call attention to works otherwise well hidden, and to avoid the construction of fresh trenches immediately before an attack which would reveal the fact that an attack was intended. Work done on buildings themselves is easily concealed from air observers, but the existence of trenches around or leading to a building gives a clear indication of its occupation.

121. **Buildings.**—Substantial buildings found close to the line of defense may be demolished or they may be occupied. The decision depends generally on two points, whether they have cellars which can be improved into good cover and whether it is possible to demolish them. Buildings draw artillery fire and unless good cover can be constructed in connection with them they are nothing but shell traps. Solid blocks of buildings with cellars can be made into good cover as a rule and had better be occupied. A building without cellars may be left out of the line if it can be so effectively demolished as to afford no cover to the enemy.

122. **Woods.**—A position from 30 to 50 yards inside the edge of the wood will afford concealment from observation and accurate artillery fire and will deny the edge of the wood to the enemy. The front edge should under no circumstances be occupied as it furnishes an excellent range mark for the hostile artillery.

If a wood has to be left unoccupied in the immediate front of an intrenched line special arrangements must be made for the concentration of fire on the near edge of the wood and on the ground between it and the front trench.

123. **EXECUTION OF FIELDWORKS.—Tracing** is the operation of marking on the ground the lines which determine the horizontal limits of cutting and embankment. **Profiling** is the operation of indicating the actual positions of such lines and slopes as are necessary to determine the proper sectional dimensions of trench, ditch, and parapet.

Tracing and profiling are not independent operations. The trace depends upon the profile and the profile upon the trace. They will be considered together under one title. For shelter trenches the profile is standardized, and the proper parapet results from the excavation of the necessary trench. The trace may be roughly determined as circumstances permit. The alignment of a line of skirmishers will do, if nothing better is possible. Heavy works will not often be built under fire, but if they are, the same rules must govern. For such works, executed deliberately, the following plan may be followed:

(1) (*a*) Establish the trace. Place the eye at the level of the interior crest.

(*b*) Mark out the trace with stones or stakes.

(*c*) Mark out the points of change of direction (maximum 120°).

(*d*) Mark the position of each traverse after each squad of 6 or 8 men (minimum thickness of traverse 2 yards).

(2) Place the men with their **arms** and **tools** by such steps as the tactical conditions of the moment demand.

(3) Place the packs and rifles on the rear side, the rifle within reach.

(4) Mark out the tasks in width and length by means of a mark made on the ground with a pick. Mark out the traverses to be made.

(5) Strip the grass from the width of the excavation. Make rapidly with these fragments of earth and grass a mask or small parapet, with steep slope on the side of the workers; raise it to 16 inches. (The piling up of earth on it will reduce it later to 1 foot.)

(6) Dig as nearly vertically as practicable. The slope should not exceed 10/1, except around the traverses, where it may be reduced to 15/1 or 20/1. As soon as the parapet affords sufficient protection, the workers, designated beforehand, make the traverses. They are commenced at the two ends.

(7) Conceal the trench by means of turf taken previously from the sites of the parapet and parados and give to these the appearance of the original ground.

(8) Arrange communications concealed from view (by brush, etc.).

(9) Proceed with the individual and collective arrangements (firing banquettes, notches or loopholes, drainage, shelters (overhead cover), revetment, steps, ladders, obstacles, etc.)

124. (A) **TOOLS AVAILABLE:**

Portable tools for each infantry company—

34 pick mattocks with carriers.
17 wire cutters with carriers.
8 hand axes with carriers.
9 bolos with scabbards.
68 shovels with carriers.

Of which each squad carries—

2 pick mattocks with carrier.
1 wire cutter with carrier.
4 shovels with carriers.
1 hand axe or bolo with carrier.

Heavy intrenching tools for each infantry regiment—

26 axes. 7 crowbars. 150 pick mattocks. 450 sandbags. 13 saws, hand. 13 saws, two-man. 300 shovels.	Carried on one intrenching-tool wagon (escort wagon).

Every infantry battalion combat train carries 16 axes, 16 pickaxes, and 16 short-handled shovels supplied by Quartermaster Corps. (G. O. No. 39, W. D., 1915.) Every escort wagon supplied by the Quartermaster Corps is equipped with 1 axe, 1 pickaxe, and 1 spade, which in an emergency might be impressed for use in intrenching.

(B) **TOOLS FOR CAVALRY:**

Portable tools for each cavalry troop—

8 hatchets, with covers.
24 picks, with covers.
72 shovels.
105 wire cutters.
1 sledge hammer.

Of which each four carries—

4 wire cutters.
3 shovels.
1 pick.

Heavy intrenching tools for each regiment—

26 axes. 7 crowbars. 150 pick mattocks. 13 saws, hand. 13 saws, two-man. 300 shovels. 450 sandbags.	Carried on one intrenching-tool wagon (escort wagon).

Every cavalry squadron combat train carries 16 axes, 16 pickaxes, and 16 short-handled shovels supplied by Quartermaster Corps. Every escort wagon supplied by the Quartermaster Corps is equipped with one axe, one pickaxe, and one spade, which in an emergency might be
ed for use in intrenching.

When a cavalry or infantry regiment is attached to and serv-
a brigade or a division, the intrenching-tool wagon and con-
l be transferred to the commanding officer of the engineer
brigade or division. When the regiment is permanently
the brigade or division the intrenching-tool wagon
erred to the commanding officer of the supply company

of the regiment. In cases of transfer, formal invoices and receipts should be used.

When in the engineer train, intrenching-tool wagons and outfits are not reserved for the particular regiments to which they pertained prior to transfer to the train, but are to be assigned as circumstances require. Sometimes several outfits may be profitably utilized by a single regiment.

126. **Working parties** should be made up, so far as possible, of entire organizations. A battalion should be ordered to send one, two, or three companies; a regiment, one or two battalions; and a brigade, one or more regiments.

The party is divided into two or more **reliefs**, and here also the principle of keeping organizations intact applies. If a regiment is to be used in three reliefs, each should consist of an entire battalion. This should be adhered to even if it makes reliefs of somewhat unequal strength. The total number of privates should be one-sixth more than the number of men that are to be worked simultaneously.

Reliefs are regulated by work rather than by time. The amount of work to be done by each relief must be plainly indicated and the officers and noncommissioned officers of each organization are responsible that their men do the quantity of work assigned to them. As soon as any organization has accomplished its work it should be dismissed.

127. **To place a relief on the work,** the organizations comprising it approach the tools in column of files, rifles slung, pass between the piles of tools, shovels on the right and picks on the left. Engineer soldiers at each pile hand tools to the men as they pass, each man taking a shovel in his right hand or a pick in his left. The corporal or squad leader places himself alongside the rear file of his squad and one of them takes a pick and the other a shovel. In soft ground, one pick to two shovels should be furnished; in hard ground, one pick to one shovel.

Proceeding in suitable formation to one flank of the line and approaching it in column of files, the head of the column parallel to and about 3 yards in rear of the rear cutting line, the column forms in line to the flank at 5-foot intervals, the corporal and the rear file of each squad falling out and taking post in rear of the squad. The interval is most conveniently maintained by having the men extend the arms horizontally and touch hands. Each organization is assigned to a particular part of the line and goes to it and deploys independently of the rest. If the line is long, guides should be furnished to direct the head of each column to the point where its deployment is to begin. **At night guides must always be furnished.**

As the men are posted, each lays his shovel 5 feet behind the cutting line, parallel to it, and drives his pick into the ground on the line at the left side of his task. Rifles and equipment are removed and placed three paces in the rear, butts of guns to the front. The corporal or squad leader and the last file of the squad take their places in rear of their respective squads and place their equipments in the line with the rest. The corporal acts as superintendent or foreman of the squad during the work, and No. 8 is a reserve, to be put in when necessary to expedite the work of the squad or to take the place of a man who is obliged to fall out for any cause.

128. **Tasks.—The capacity of the average untrained man** for continuous digging does not much exceed 80 cubic feet for easy soil, 60 cubic feet for medium, and 40 cubic feet for hard soil. He will do three-eighths of this in the first hour and five-eighths in the first two hours, and the other three-eighths in another two hours, making an hourly average of five-sixteenths of the task for the first and three-sixteenths for the second two hours. In addition to the fact that he works but a little over half as fast in the second two hours, four hours' work will leave him unfit for fighting or marching, while after two hours' work he should be able to do either. The quantity of work assigned to each relief should be that which can probably be done in

two hours, and the relief is required to finish it and no more, whether it takes less or more time. For the first work the soil is apt to be loose and the lift is less, so that a slightly greater task should be given to the first relief than to the second. Assuming men at 5-foot intervals and neglecting fractions, the number of hours' work required to throw up a parapet is the section of the parapet in square feet divided by 5 for easy, 4 for medium, and and 2½ for hard soil.

129. **Placing the workers and executing the work.**—The men are divided into working groups composed of those who are to work at a common task. Group tasks are laid off at such intervals up to 5 feet, as may be determined by conditions affecting the work, as time available, tools, character of the work, and the soil.

Begin work by digging downward so as to cover oneself from the front as rapidly as possible. Commence the parapet in such a way as to make rapidly a mask with a steep slope on the side of the workers, Work under fire is done at night. The men must keep absolute silence, lie down immediately on the ground when rockets appear, and resume their work when the light has disappeared.

130. **Double gangs.**—When men are plenty, tools scarce, or time presses, a task may be completed in about two-thirds of the ordinary time by detailing two men at each set of tools. In this case the organizations march to the tools in columns of twos, the right file taking shovels and the left file picks. The two gangs change off at frequent intervals and the men work as rapidly as possible.

131. **Shaping bottom of trenches.**—The digger left to his own devices will make the bottom of the communicating trench concave; the mud will then settle to the center, which the men's feet will soften and gradually wear down. When the trench is cleaned the mud will be taken out in a series of holes along the center, making walking very difficult. This is a detail that should be insisted on when work is going at a high rate in the first line and a shift of workers is on every night. It has been reported that more men are injured by sprains than by hand grenades and bombs, and a sprain lays a man up for a month. The bottom of the trench should therefore be made convex or rounded upward just like the cross section of a good road. No other form should be allowed.

132. **Stairs or steps** from the bottom of communicating trenches to the ground level are important at all crossings where possible ,and bridges over lateral trenches will furnish practically a roadway parallel to the main communicating trenches for use at night or during an intermission in the artillery bombardments.

133. **Construction under fire.**—The first object is to get some sort of cover as quickly as possible for the firing line. The individual men start to dig pits for themselves just where they are stopped by the enemy's fire. As soon as may be these pits are then joined to form a continuous firing trench. This trench may form the ultimate front firing trench and the cover trench be subsequently dug back of it, or it may become the cover trench, and new firing trenches may be dug in front by pushing forward at intervals. The question of proper traverses for the final trench should be considered in the spacing of the first constructed pits and in joining them up to form a trench. It is desirable to have traverses formed out of the original undisturbed ground.

If the first dug trench is to form the cover trench, the next step after completing it is to push forward T-heads to the front to form the firing bays.

The work of digging the individual firing pits will be begun by the infantry troops generally with their intrenching tools. Troops should, therefore, be well practiced in digging themselves in by night or day with these tools.

Heavier, more effective tools should be brought up to the firing line as soon as possible, and every plan for an advance should provide for *a certain* number of digging tools in addition to the intrenching tools *accompanying the* attack, and this number should be supplemented as *rly as possible* by every pick and shovel available.

It may be necessary to wait until dark before a large number of tools can be brought up and serious work attempted, but it is sometimes possible under the covering fire of artillery to dig a continuous trench by day. In any case every effort must be made to get good trenches dug as soon as possible and one of the first things to do is to get some wire entanglement in front of the trench, as this gives a feeling of security to the workers.

During the first day or two the new line will be bombarded heavily and probably counterattacked. If the front trench is constructed in the first instance very close to the enemy's line it is particularly vulnerable to counterattack, and if the enemy succeeds in breaking through the line at a time when there are no defenses prepared behind it he may force a retirement on a large front. The construction of support trenches 100 to 200 yards in rear of the front line and of reserve trenches should therefore be proceeded with simultaneously.

134. **At night.**—If the offensive open attack has to be given up temporarily and the enemy is found in a prepared fortified line a more gradual and concealed method of approach has to be adopted. A line of trenches is constructed in the first place at quite a distance, say 500 to 600 yards or even more, from the enemy's front trench, the exact distance depending on the ground and the facilities for cover. This line is made fairly strong and complete before any further advance is attempted. Then under cover of darkness or fog and perhaps of a heavy bombardment of the enemy's front line a new trench is constructed at a distance of 200 to 300 yards from the enemy. From this line further advance is usually made by sap. The advantage of this method is that before any attempt is made to dig a line within easy reach of small counterattacks, there is a completed line ready behind the new line, to stop further progress by the enemy if the new line is counterattacked and broken.

135. **Employment of engineers.**—The numerical insufficiency of engineers both during the preparation of the terrain and during the combat has developed in more than one case during the European war.

As soon as the first wave of the assault starts, engineer units (or other troops) posted previously should connect the parallel of departure with the enemy's first-line trench. When this part of the terrain has been crossed by approach trenches there will be covered approaches right into the enemy lines. It is not sufficient to give general orders about this matter; the attack order must specify accurately that such and such approach trenches will at once be prolonged to the conquered trench so that everyone will know in advance and make use of them the first day. These could well be used by artillery observers who must personally follow closely the infantry attack, and then come back through these trenches and telephone instructions or information to their batteries in regard to the points reached by the infantry.

SIEGES.

136. The attack by regular approaches of a strongly fortified place involves mainly the principles and devices previously discussed, but their employment is under conditions so different from those resulting from the contact of two mobile forces as to require separate treatment. What follows is not a complete presentation of the subject of sieges, but only of such features as are concerned with engineering duties on the side of the attack.

The differences referred to are principally—

Guns of heavier caliber will be encountered.

The terrain being well known to the defense, all fire will be more accurate.

High-angle fire will be extensively employed, and angles of fall of 30° and greater must be expected.

Some trench work must be executed under close fire and must gain ground to the front. A variation either way from its proper direction will lose ground or else expose the trench to enfilade, so that accurate tracing is of great importance.

At the same time these conditions of sieges are more alike in different times and places than those of operations with mobile forces, and the best ways of doing some things can be stated for sieges with more confidence than in the case of ordinary fieldworks.

137. **The first step** toward the reduction of a fortress is to cut off communication of the occupants with the outside world. This is done by a rapid movement of a relatively small force followed by reinforcements sufficient to hold a line entirely around the place and beyond the range of its artillery, say, 2½ to 3 miles from its main lines of defense. This line is called the **line of investment,** and the belt of territory immediately outside of it occupied by the investing force is called the **zone of investment.** Whether this line must be occupied continuously will depend upon its nature. As much must be actually occupied or commanded as could be used by the besieged for exit or entrance. The line of investment is divided into sections, preferably so chosen that a unit of command can be assigned to each.

138. **Troops assigned** to a section of the zone of investment begin at once to reconnoiter it and put it in the best possible state of defense. **Artificial or accidental features are prepared** and strengthened, **intrenchments** thrown up where required, **communications** made and improved through and between sections, and **telegraph** and **telephone** lines established around the zone and to headquarters. Every means must be utilized to gain knowledge of the ground inside the zone. The time which must elapse before the siege material can be brought up will permit a great deal of such work to be done.

The real attack or systematic approach is pushed inward from a few points only of the zone of investment, usually one or two. The side on which these approaches are to be made will be determined by the following conditions:

(1) The best communication with the base.

(2) The best terrain for battery positions and approaches under natural cover.

(3) The most favorable ground for construction and operation of siege railways.

(4) The easiest digging.

(5) The most important consequences of success.

The first condition will usually be controlling, unless one of the others is prohibitory. If the zone of investment is favorable and ample siege railway equipment is available, the attack may be conducted from points somewhat removed from the main terminus of the supply line.

139. **The main defensive** line of an important fortress will consist of a series of detached forts. To breach such a line one fort at least, more often two, must be taken, and during the operation the fire of the one on each side must be kept down. If two forts are to be reduced, the siege will consist of artillery work against four and trench work against the middle two of these.

When the front of attack is decided the **main engineer park** is located, out of reach of the defenders' artillery, convenient to the front selected and to the main supply line, and connected with the latter by good communications. Here is assembled all the siege
pertaining to engineering operations as fast as it arrives,
ted and arranged in convenient shape for selection and
to the front as required.
the main siege batteries are next selected, at mod-
ange from the forts, 2,500 to 4,000 yards, and for
parks near them to contain materials for the con-
and supply of the batteries. These sites are con-

nected by a belt railroad immediately in their rear, and the belt line is connected with the main park at one or more places.

140. **The complete investing force** must be heavily reinforced, ordinarily about doubled, before siege operations on any considerable scale are undertaken. The additional force will be concentrated along the front of attack, mainly toward its center. This and the investing force along the front of operations are sometimes called **siege troops,** and the remainder of the investing force distinguished as **investing troops.** The siege force should consist of infantry, engineers, and artillery in the proportion approximate of 83 per cent, 5 per cent, and 12 per cent, respectively, with the proper contingent of the Signal and Hospital Corps and supernumerary engineers and ordnance officers. The total attacking force will range from 2½ to 4 times the strength of the garrison.

141. **The siege artillery** will probably be disposed in batteries of 4 pieces or less, dispersed as much as concentration of fire will permit, and sited when possible on the reverse slopes of ridges or hills, or behind timber, and will employ indirect fire almost exclusively.

Though batteries are invisible, the high-angle fire of the defense will reach them, as the enemy's artillery will systematically search all reverse slopes within range, and the effect of shells must be localized by artificial cover. An emplacement for each gun will be best. A light parapet across the front and on the sides will answer. A 4 to 1 slope is the most convenient inclination of ground. Figure 122 shows a typical emplacement for such a slope. Ample bombproof cover for men and reserve ammunition should be provided, preferably on the flanks. Figure 121 shows half plans of two types used by the Japanese.

On level ground the platforms may be laid on the natural surface, the guns surrounded by a splinter-proof wall, in which case rooms of sufficient size may be walled off between the guns to form service magazines. The floors of the magazines may be depressed sufficiently to permit a weatherproof room to be thrown over the ammunition, below the crest of the wall. The drainage of the roof must be intercepted before it runs into the pit.

142. **First parallel.**—When the siege batteries have brought the artillery fire of the defense under control the first attempt to gain ground to the front is made by opening a trench generally parallel to the line of investment and, if possible, within 1,200 yards of the enemy's main line. During the day the outposts are advanced to or beyond the proposed line, to permit it to be reconnoitered and its bearings noted. At night the attack is pushed more strongly and the enemy driven in as far as possible for the greater safety of the working parties.

Tracing.—As soon as it is dark enough for concealment the tracing is begun. Each party consists of one engineer officer, one noncommissioned officer, and a private for each 50 yards of line to be traced. The outfit consists of tracing tape, pegs, mallets, and measuring rods. The tracing tape is of white cotton, 50 yards long, ⅜ inch wide, and marked at 5-foot intervals by weaving or printing. It is provided with a loop at each end to attach to a stake or to another tape. The officer must provide himself with a compass and means of reading it by artificial light. (Reconnaissance.) There should be a tracing party for each 800 yards of line, at least, and more will be better, as the time spent in tracing is lost for digging. It will be most advantageous if the tracing can be put through during the twilight, while it is still light enough to see the ground and read the compass, but too dark for the defenders to see the parties. The parties are paraded, outfitted, and moved up as close as possible before dark.

The officer, provided with a description of his initial point and the bearing or course of the line from it, proceeds to it, his party following in single file. Having identified the initial point, the offi-

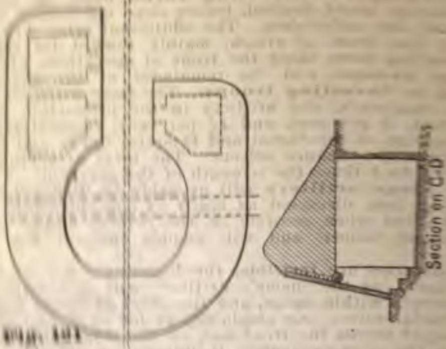


Fig. 121

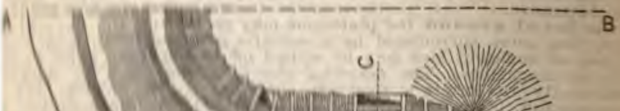


Fig. 122

stations a sapper there, faces him in the direction of the line, and taking the end of his tape, marches along the line to be traced, followed by the remainder of the party. When the tape is nearly run out the sapper checks it, and, as the end is reached, sets a stake between his heels and puts the loop of the tape over it. The officer stations the second sapper at the front end of the first tape, facing in the direction of the line, and proceeds as before. When the second tape is run out the second sapper sets his peg and puts the loop of both tapes over it. The operation is continued until all the tapes are down. The officer returns to the rendezvous of the working party and conducts it to the line. Each sapper lies down at his peg, facing the initial point, and upon the arrival of the working party assists in the extension along his tape.

If the fire of the defense is not sufficiently under control, it will be necessary to have the outposts begin the first parallel by digging pits, or short lengths, which can afterwards be extended to a connection.

143. **Approaches** or zigzag trenches must be traced and dug on the same night with the first parallel, connecting it with cover in the rear. There should be at least three such approaches—at right, left, and center.

The typical trace of such an approach is shown in figure 123. The **branches** or **legs** AB, BC, etc., must have a direction such that when prolonged they will pass outside of the extreme point on the corresponding flank from which the defense can bring fire to bear. A leg will usually be not more than 100 feet in length.

The tracing of approaches for simultaneous digging differs in detail but little from that of the parallel already described. It is more difficult because the line is broken, and greater accuracy is required. Each tracing party is given an extra man for each angle. The tape is run continuously, and, as each angle is passed, the extra marker stationed there cuts the tape 9 feet from the angle on the back course, makes the long end fast to a peg at the cut, and stretches the short end in prolongation of the forward course (fig. 124) to mark the direction of a return carried across the end of the back leg to protect it from enfilade. The return may be from 10 to 20 yards long. It can be prolonged from this short end of tape without further tracing. Approaches so traced are dug simultaneously over their entire length the same as the parallel.

144. **The digging of approaches under fire** differs from ordinary trench work in that it is done progressively from one end and with the men reasonably protected from fire while doing it. Tracing is dispensed with. Approaches are usually called **saps,** the operation of digging them **sapping,** and the skilled men **sappers.** The end at which digging is in progress is called the **saphead.**

So long as the legs can be given the direction described in paragraph 143, cover is needed on the end and one side only. This form is called **single sap.** A single sap gaining ground to the left is called a **left-handed,** and to the right a **right-handed,** sap. The shovelers work right-handed in a left-handed sap, and the reverse.

When the saphead is very close to the enemy's line, such direction can not be given, and cover is required on the end and both sides. This form is called **double sap.**

Single sap.—A party of one noncommissioned officer and 8 sappers in two reliefs works at the saphead. The two leading sappers, Nos. 1 and 2, excavate a trench 4½ feet deep and just wide enough to work in, throwing the earth to the front or exposed side. They are protected in front, or on the end of the trench, by a pile of half-filled sand bags, 50 or 60 in number, piled so as to make a parapet 2 feet high. The sand bags should be smeared with mud so as to show the color of the soil. No. 1, kneeling or crouching, undercuts the end breast a few inches and brings down the earth. He steps back and No. 2 takes his place and shovels the loose earth out. No. 1 returns, throws forward as many sand bags as may be necessary to gain ground, using a fork or rolling them over with his hands. He then undercuts again and the operation is repeated. Nos. 3 and 4 widen the trench 2 feet and raise the parapet, also forming a berm 12 to 13 inches wide.

The rate of advance of a sap is only 2 to 4 feet an hour. When half a yard has been gained, Nos. 1 and 2 exchange places and when a yard is gained the other relief comes in. At each change of reliefs the men who were Nos. 3 and 4 on the last tour take 1 and 2. Casualties are made up from the waiting relief. Generally, unless reduced to less than 4 men, the detachment must work without reinforcement until the regular change of trench reliefs.

A working party of infantry, 25 feet in rear of the sappers, widens the trench to 10 feet. Figure 125 shows a plan and sections of a single sap, and figure 127 gives a perspective view of a left-handed single sap in progress.

Double sap.—Two parties work parallel to each other, Nos. 1 and 2 leaving a 4-foot tongue between them, which is taken out by Nos. 3 and 4. No widening party is required. Figure 126 shows a plan and sections of a double sap.

To prevent enfilade the direction of the trench is changed at right angles as soon as the plunging fire becomes too annoying. After going 25 to 30 feet laterally, the trench turns again to the front, and, after having advanced sufficiently to form a traverse, turns again to the right until it reaches the original line, when it resumes the main direction. Figure 128 shows the plan of such a sap. It is called a **traversed sap.**

145. **Second parallel.**—The first infantry position established, a second one well advanced is the next objective. It is called the **second parallel** and should be 500 or 600 yards from the enemy's works, or about midway in front of the first parallel. It will envelop only the work selected for attack and will thus be shorter than the first. The second parallel, and the approaches to it from the first, may be established in a night, like the first parallel and its approaches, though this will be the exception. With an alert defense the advance from first to second parallel must be by sap. When the heads of the saps are abreast of each other and on the desired line they may be turned toward each other and run to a connection, forming the second parallel, though, if possible, the work should be expedited by extending parties for simultaneous work.

146. **Third parallel.**—This will be about halfway from the second parallel to the enemy's works and will in most cases be the position of assault, though sometimes fourth and even fifth parallels have been found necessary. At this close range attention is necessary to guard the sapheads, which can be done by machine guns and rifle fire from the second parallel. As the saps advance the returns may be lengthened and turned so as to form demi-parallels. This will enable a stronger guarding force to be kept under shelter and well advanced to repulse sorties or to take the offensive if opportunity offers.

147. **Simultaneous work.**—The preceding discussion shows the most systematic method of procedure with the least losses. However, if the enemy's artillery is fairly well under control and if the terrain is at all suitable, two or more of the parallels or demi-parallels may be constructed at the same time. This result is obtained by sending working parties at night to the position of the advanced parallel or demi-parallel, and these parties hurriedly construct enough of the parallel to obtain shelter against the enemy's fire. During the day and subsequent nights this parallel is completed and the approaches to it are more quickly constructed because working parties are actively engaged at both ends.

148. **Fourth and fifth parallels.**—It is quite often necessary to construct a fourth and fifth parallel in order to maintain troops near the sapheads and protect the sappers at work.

The foregoing description of siege works embodies principles but not complete practice; the latter is greatly affected by accidents of ground. Figure 129 is a general view of the trenches actually constructed by the Japanese in the attack on Fort Kuropatkin. Especially interesting is the traversing of the ravine or gully on the left, which then became a good approach. Such ravines were characteristic of the terrain around Port Arthur, and much work of this kind was done by the besiegers. Sometimes the traverses were only planks laid across from bank to bank with sandbags on top, allowing passage under them. The distances between the traverses and the height of the sandbag protection were so regulated that a shot grazing one could not pass under the next.

149. **Direct advance.**—Eventually the sapheads will be so close to the enemy's position that zigzag approaches are not effective in gaining ground to the front, because their directions are almost parallel to the parallels in order to prevent enfilade from the enemy's position. In this case the sap is driven straight for the enemy's position, as shown in the traversed sap (fig. 124).

When the traversed sap is no longer effective as compared with the ground gained to the front, it is necessary to resort to mining (as described later) or to assaults.

TRENCH WARFARE.

150. When the advanced positions of both sides are close to each other there ensues a series of conflicts which have been designated by the term "trench warfare." In sieges the forces in closest contact are the advanced parallel, saps, and mining galleries on the side of the attacker and the intrenched position and countermines of the defender; in extended intrenched fronts the forces in closest contact are in the firing trenches, saps, and mines and countermines of the two sides.

The methods of conflict in trench warfare are practically the same as in former wars, with modifications due to the advances in science. Hand grenades, bombs, obstacles, etc., were used at Sebastopol, Port Arthur, and at Verdun in 1916.

The **essential difference** between capture of intrenched places and victory over extended intrenched fronts lies in the fact that the garrison only of the fortress must be subdued while the nation back of an extended intrenched front must be subdued. While the garrison of a fortress still retains numbers, food, ammunition, and morale it may be possible to capture local strong points, but the garrison will not surrender as long as its power of resistance is not broken; other strong points to the rear will be occupied and the resistance continued. Similarly, while the nation still retains numbers, food, ammunition, and morale it may be possible to capture local strong points and force the abandonment of an extended intrenched line, but the nation will not cease making war until its physical or moral power of resistance is broken; other extended intrenched lines to the rear will be occupied and the resistance continued.

The **objects of trench warfare** are thus twofold: First, to capture local strong points; second, to break down the resistance of the enemy.

The following **general principles** have been accepted.

(*a*) Advance in the open is impossible against enemy fire superiority.

(*b*) Advance by open sap work is difficult against enemy artillery fire and almost impossible if enemy has artillery fire superiority.

(*c*) Advance by mining is effective if enemy has artillery fire superiority.

(*d*) An assault against an alert enemy must be preceded by an effective fire of artillery explosive shells to destroy somewhat the enemy trenches and obstacles.

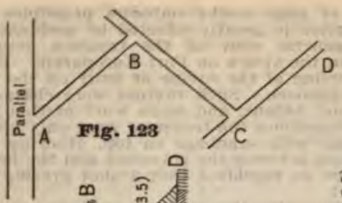


Fig. 123

Fig. 124

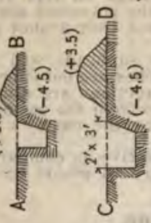


Fig. 125

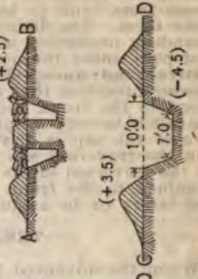
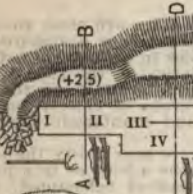
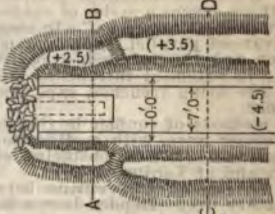


Fig. 126





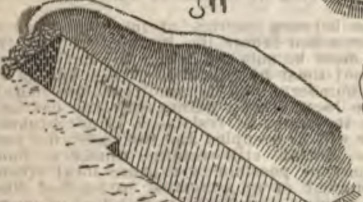


Fig. 127

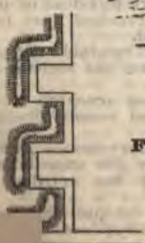


Fig. 128

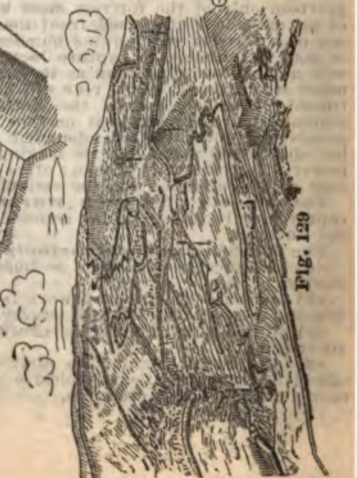


Fig. 129

(*e*) An artillery curtain of fire must be maintained beyond captured enemy trenches in order to assist the successful attackers in defending the captured trenches against counter attack.

151. **Mobile army.**—The situation on the west front in Europe illustrates the effect of having masses of trained men facing each other on a relatively short line. From the North Sea to the boundary of Switzerland the battle line extends over a distance of 430 miles. The opposing armies have each constructed triple lines of trenches, often supplemented in the rear by a double line of underground shelters where the troops in reserve may rest. Miles upon miles of passageways, saps, galleries, and zigzags afford means of communication between the trenches. To dig these field fortifications, the allies and Germans are said to have removed about two and one-half times the excavation made at Panama. At a number of points the hostile lines are less than 100 yards apart, and grenades of all types are used in great quantities. There are no flanks to turn, the lines are heavily covered by obstacles, and each side having reserves upon reserves, sapping and mining must be freely resorted to in order to gain ground. The opinion that continuous defensive lines are to be avoided since they lead to a dispersion of forces, resulting in general weakness, must be somewhat modified when enormous numbers of troops are available. Instead of a series of defensive positions with intervals, we find the opponents in two fortified continuous lines.

ACCESSORIES OF TRENCHES AND TRENCH WARFARE.

152. **Observation.**—The observation of the enemy is of first importance in trench warfare. It should give complete knowledge of all the elements of the hostile line and prompt information of any movement of the enemy. It is effected by observation from the ground and observation by aircraft.

Observation from the ground is divided into three echelons:

(1) Observation in front of the firing line from small posts and listening posts.

(2) Observation on the firing line by sentinels and lookouts.

(3) Observation in rear of the firing line, by artillery observers, sentinels, and lookouts of the shelters.

Observation in front of the firing line is effected by small posts or listening posts (fig. 1) of from 1 to 8 men placed in rifleman's pits, shot holes, organized shell craters, or in short, semicircular elements of trench, connected with the firing line by sap or low-mine gallery. Their protection is assured by their invisibility. The retreat of the observers is protected by a system of branch galleries whose entrance into the main gallery can be closed rapidly, or by a barbed-wire protection placed over the sap. The lookouts in small posts are placed in very short trenches, which are provided with loopholes. Protection at short range against grenades is secured by a network of wire.

Observation on the firing line is effected by lookout posts organized preferably at the salients where the view is more extended (fig. 1). These posts give a view over the enemy's firing line; they are provided with periscopes, range finders, and large scale maps. They should be concealed by all practicable means; observation is carried out under good conditions only when it is done without the knowledge of the enemy. The posts should preferably be constructed on the right of a traverse, and in an excavation in front of the trench wall.

The **observation posts,** even of the infantry, are not necessarily in the firing line or in the listening posts. Often in rear, points will be found which will give an excellent view, and will not attract the enemy's attention. The term "**observatory**" is often employed for this kind of observation post. The observatories generally have a more extended view than the lookout post; they are protected and have means of communication such as telephone, heliograph, messenger, carrier pigeons, wireless, etc. They may belong to the infantry, the artillery, or higher commands. The observatory may be occupied by the commander himself or by an observer who represents him. In any case the observatory is near the command post (fig. 1). It must have a low parapet, be defiladed from view, and proof against large projectiles.

The location of the lookout posts and observatories must be determined in accordance with a complete plan for each supporting point or sector of defense. No part of the hostile front should be free from observation and the parts of the front favorable for the attack of the enemy should be specially watched. An observatory should be located near the command posts of the commanders of strong points, supporting points, and sectors. Those of the last two must have extended views over the whole of the terrain.

154. **Lines of information.**—During a bombardment, the maintenance of lines of information becomes very difficult, but it must be accomplished by all possible methods, such as:

(*a*) Installing telephones under strong shelters.

(*b*) Using lead-covered cable, buried 6 feet deep, especially for the lines connecting the regimental, brigade, division, and corps headquarters.

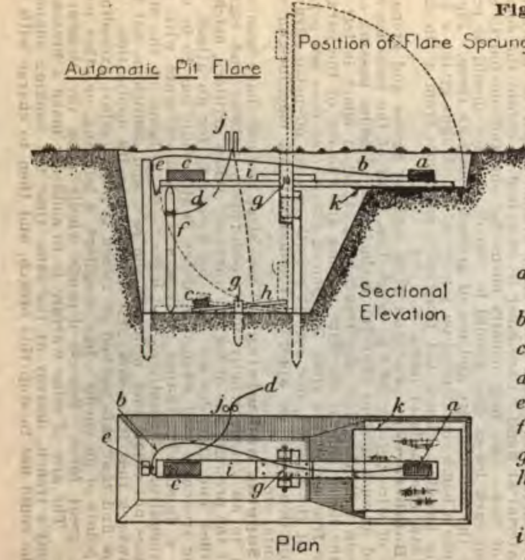
(*c*) Placing rockets in all shelters and observatories where officers or noncommissioned officers are posted.

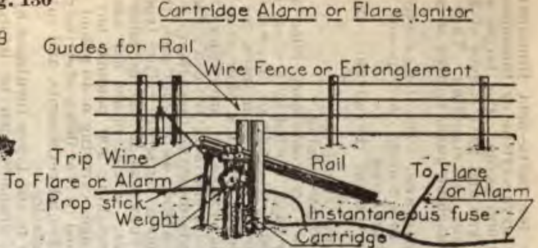
(*d*) Preparing posts for visual signaling, safe from bombardment and defiladed from view of the enemy. These posts are constructed in shelters similar to those for searchlights and are provided with horizontal loopholes with openings to the flank or rear.

The problem of the telephone is one of the most important and has yet to be satisfactorily worked out. The allowance of apparatus must be greatly increased and systematic organization of men and matériel is urgently demanded. All persons along the line, passers-by, guards, and the like must have an interest in maintaining the lines and keeping clear of the wire. Every noncommissioned officer should have a few staples or long hooks in his pocket so as to place a fallen wire temporarily out of reach of passing troops. Artillery wires should be placed on one side of the trench and infantry wires on the other; they must be high enough to clear men passing at night, loaded and weary, and at trench crossings they must be carefully protected. Constant supervision and repair of the lines is necessary. Lines with too many phones in series should be avoided. Multiply the centrals and reduce the phones on the same line to three or four.

153. **Battle-field illumination** is a necessity wherever night attacks may be expected. Portable searchlights, both animal and motor drawn, in units up to 36 inches, have become an accepted part of every army. In addition, though, to these powerful lights, trenches must be supplied with storage battery or gas reflector lights, star bombs, rockets, and flares, arranged so that they can be put into action instantaneously when an enemy approaches. The entire foreground and obstacles must be illuminated, leaving the defenders in shadow. If a light is used too close to the defenders' parapet, they themselves are illuminated and the light becomes a source of danger. Flares, etc., have been furnished in all sizes. Some burn as much as 20 minutes and light up an area of 100 yards radius. Some are thrown out to the front, as is a hand grenade; others are fired as rockets from shotguns or small mortars, and others are fastened in a tree or hidden in a pit well to the front (fig. 130). These latter are set off by trip wires stretched close to the ground, so that an approaching enemy will catch his foot in them. The best illuminant would seem to be one that could be fired well to the front from a mortar and would then hang suspended from an open parachute the enemy for a long time. These should not be used in un-
le winds. If no other flares can be had, bonfires can be laid
d ready for lighting by a quick match made of flash powder.

Fig. 130





a – Flar Composed of Nitrate of Potash, Sulphur and Orpiment.

b – Instantaneous fuse from Friction Tube to Flare.

c – Weights.

d – Trip Wire.

e – Friction Tube, for ignition of Fuse.

f – Prop stick connected to Trip Wire.

g – $\frac{3}{8}$" or $\frac{1}{4}$" round Bolt to form Hinge.

h – A Pawl or Catch Lever to prevent Flare from being tilted by wind pressure.

i – Plank carrying Flare and weights.

j – Guides for Trip Wire.

k – Reflector for Flare.

Searchlights are the most effective for battle-field illumination. The smaller ones, about 12 inches, are oxyacetylene or incandescent electric and have a range of 300 to 1,000 yards. The larger ones, 24 to 36 inches, are of the electric-arc type and have ranges of 2,000 to 5,000 yards. They can also be used for signaling. They are placed in shelters similar to those for machine guns, located so as to flank the line of fire.

155. **Some details of trench warfare.**—The long-continued proximity of opposing trenches has led to scientific development in—

1. The use of trench bombs and hand grenades.
2. The use of asphyxiating gases to conceal the advance and to destroy the enemy in his trenches.
3. The use of fire, both offensively and defensively.
4. The extensive use of mining and countermining.

156. **Grenades and bombs.**—These are containers filled with high explosive designed to be thrown by hand, hurled by a sling, fired as a rocket or from specially constructed bomb guns, or dropped from aerial craft. They burst either by time or percussion fuses, may be improvised in a variety of forms, and are useful in a close attack or defense. As in the case of other high-explosive projectiles, their material effect is very local, although demoralizing to men's nerves. Incendiary grenades have been used containing the ingredients necessary for making the welding compound known as thermit and, therefore, throwing molten metal about upon bursting. The type of grenade causing the most havoc is that known as an "aerial mine" or "winged torpedo" (figs. 131 and 132). Aerial mines are usually much heavier than torpedoes, often weighing 200 pounds, but the latter obtains greater accuracy and range, carrying a 40-pound projectile about 500 yards. Both may be used to beat down effectively the enemy's defenses, destroying his sandbags and revetments, and cutting away wire entanglements and other obstacles.

157. **Hand grenades.**—In addition to the types furnished by the supply departments, many good hand granades can be improvised with material at hand. Care must be exercised to obtain the correct length of fuse. One inch usually burns for one and one-fourth seconds, but each lot of fuse should be tested. Troops should be practiced in the manufacture and use of grenades such as these. Figure 133 shows a bomb constructed on a piece of wood, thus giving a good throwing handle. Figure 134 illustrates one made from a tin can; figure 134a, one made of nails.

158. **Bomb screen.**—For protection against bombs and grenades a grille of wire netting may be erected in front of the trenches and arranged at such a slope that the majority of grenades passing over the screen will also clear the trench (fig. 136.) A space is left between the lower side of the wire netting and the top of the parapet to allow free use of the rifle. Of course, this screen does not permit the use of the bayonet, nor does it permit an easy offensive advance. This objection does not apply to communications, machine-gun emplacements, etc.

159. **Sapping and mining.**—These siege methods have been carried on to an extent wholly unprecedented—a natural and logical effect of the present type of trench warfare. When artillery, machine guns, rifles, and grenades are used for preparing for an attack, the opposing trench is well warned, and the final assault has to be carried to a finish with chance of results not commensurate with the large expenditure of munitions and loss of life. Mining, on the other hand, does not entail such a drain upon men and munitions, but has the drawback that it is slow and restricted in its application. We therefore find that this method of attack is used against exceedingly strong points of an enemy's line, a salient, a building, or other point held in great force. Success depends wholly upon the element of *surprise*. The aim of mine warfare is to suddenly make a breach in *the enemy's trench*, destroy at the same time the flanking supports *which he could* use to stop this breach, and then to charge with the

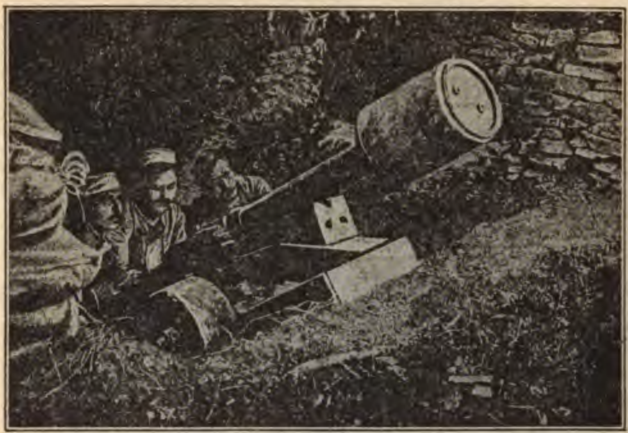


Fig. 131

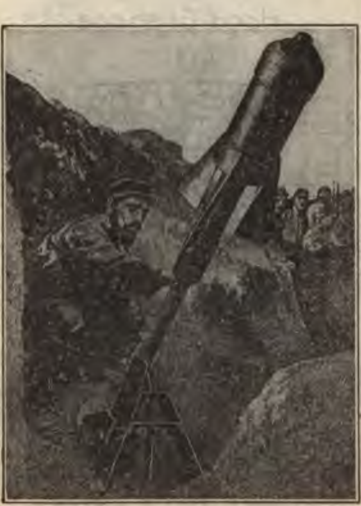


Fig. 132

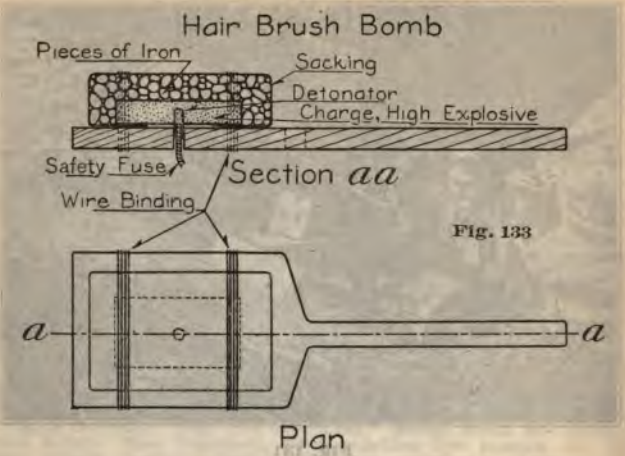


Fig. 133

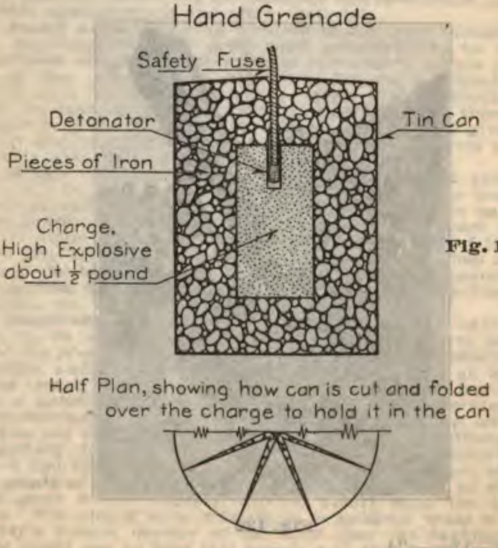

Hand Grenade
Safety Fuse
Detonator
Tin Can
Pieces of Iron
Charge, High Explosive about ½ pound
Half Plan, showing how can is cut and folded over the charge to hold it in the can

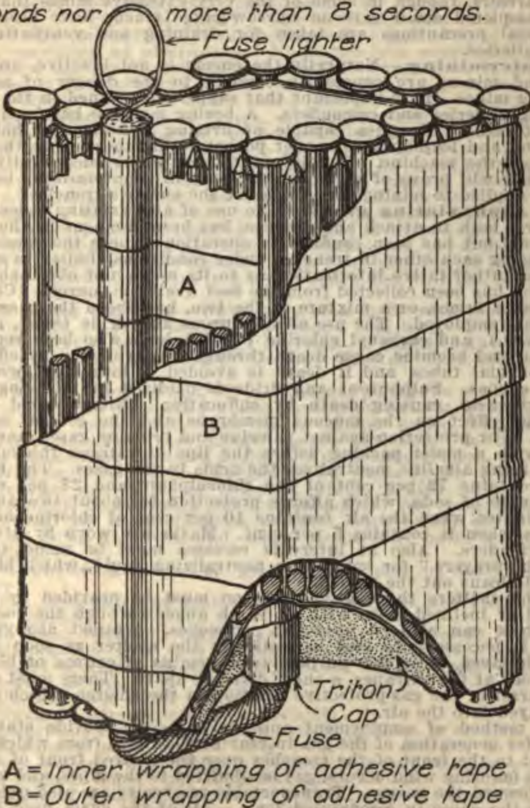
Fig. 134

Fig. 134 a

HAND GRENADE

Triton block and one layer of 16d nails wrapped with adhesive tape. Wgt. 1¼ #

Cut fuse to burn not less than 5 seconds nor more than 8 seconds.



A = Inner wrapping of adhesive tape
B = Outer wrapping of adhesive tape

troops into the enemy's trench disorganized by the explosion of the mine, and there to entrench before the opposing forces are able to recover.

160. **Mining methods.**—Mine galleries are usually started from the sapheads that have been pushed well forward into the zone of obstacles and which allow the miners to advance rapidly under cover until almost within range of the enemy's grenades and bombs. Military mining is well explained in the Engineer Field Manual, though it is found that in war improvised use is made of whatever methods and appliances of commercial mining may be found practicable. One great difficulty has been the removal of the earth resulting from the digging. Most often it has been taken away in sacks or relays of wheelbarrows, though in some of the very extensive mines that have been completed small cars on narrow-gauge tracks have been used. The usual precautions are taken for draining and ventilating the mine galleries.

Countermining.—Naturally the enemy is not inactive, and sappers and miners are constantly exposed to the danger of meeting opposing mines. It is important that sappers be trained in the use of listening galleries and camouflets. A boring machine has been developed of late in America capable of driving a horizontal hole and enlarging and loading a camouflet pocket at distances more than 500 feet from the machine. If this outfit operates as successfully as is claimed it will prove of great use not only in countermining but will also be applied to mining direct against the enemy's trenches.

161. **Asphyxiating gases.**—The use of asphyxiating gases as an auxiliary, both in attack and defense, has been frequent in the European war, but has been confined to operations where the combatants were facing each other in trenches under conditions similar to a siege.

While authoritative information as to its use is not obtainable, the following has been collected from the best available sources. Chlorine or bromine fumes, or a mixture of the two, have been the gases most commonly employed. The use of sulphurous anhydride (SO_2), nitrous acid (N_2O_4), and carbonyl chloride ($COCl_2$) have also been reported. Chlorine and bromine cause death through strangulation by effect on the bronchial tubes, and if death is avoided, a long slow bronchial illness ensues. Sulphurous anhydride is oxidized in the lungs into sulphuric acid, causing death by suffocation. Nitrous acid causes death by effect on the mucous membrane and the central nervous system. For protection against chlorine and bromine gases masks are worn with a moist packing before the lips of nitrous thiosulphate, which, being alkaline, neutralizes the acids in the gases. The English mask contains 72 per cent of the thiosulphate and 28 per cent of bicarbonate of soda, which affords protection for about two and one-half minutes when the air contains 10 per cent of chlorine and five minutes when it contains 5 per cent. Masks are worn by attackers and defenders. Also at intervals recesses must be made to hold "trench sprayers" for spraying a neutralizing liquid, which kills the gas and cleans out the trench.

In the shelters thorough ventilation must be provided by boring vertical or inclined holes with an earth auger through the roof (fig. 1). These can also be used for periscopes. Against asphyxiating gas it is necessary to seal hermetically the shelter as soon as the alarm is given. For this purpose two curtains of canvas or blankets are placed at the entrance, a short distance apart. There must always be a barrel of the gas-protective solution in the shelter, which should be sprayed into the air.

The method of employment appears to be to provide stationary works for generation of the gas in rear of the lines, from which pipes are laid to the front of the trenches over the desired front of attack. When a favoring wind occurs, gas is admitted to the pipes, and issuing, fts toward the enemy. Transportable reservoirs are also used, con- ing the gases in compressed form. All of the gases used have a specific gravity, which causes the poisonous clouds to lie close to round and remain concentrated for a considerable time.

It has been reported that the French are manufacturing a trench grenade which liberates a chemical liquid giving off a gas that excites the lachrymal glands and impairs the vision.

162. **Attack on entanglements.**—Regarding methods of crossing wire entanglements, it is said that a great deal of time and thought has been spent on experiments on this matter, and various schemes have been tried, such as carrying a roll of wire netting to form a bridge and throwing it over the entanglement, figuring on the spring of the uncoiling roll to carry it over, also throwing sheets of expanded metal over the obstacle, and a rather clever mechanical device, which can be operated by one man, and by which wire netting is stretched and thrown some 25 feet. These schemes are of doubtful value, the material being too heavy and cumbersome to carry across a fire-swept area. To clear the enemy's wire entanglements is a task for artillery or for the individual infantryman with a pair of hand clippers.

163. **Guarding of obstacles.**—No matter how complete a system of obstacles has been established a constant watch over it must be maintained if it is to fulfill its rôle successfully. In positions where there is a likelihood of the trench being rushed or of the enemy sneaking through under cover of darkness, saps must be pushed forward into and beyond the entanglements, so that sentries may be placed well to the front in listening posts and rifle pits. After a sentinel gives the alarm and is ready to retreat to the main trench he closes his communicating sap to the enemy by lowering wooden frames, covered with barbed wire across the sap somewhat in the nature of a portcullis. Much ingenuity has been shown in constructing alarm traps and wire trips for the purpose of setting off flashlights, firing pistols, or ringing bells upon the approach of an enemy. Trenchscopes, permitting a safe view to the front, are quite essential. They are very simple periscopes, consisting of parallel mirrors in a long wooden box, both set 45° to the long axis of the box.

164. **Rolling shields.**—These have been made with cross section like a plus sign (+), the arms being about a foot long. These shields are about 3 feet in length, so that they can be rolled to the front by one man, giving him very good protection. They are of doubtful value even at sapheads.

165. **Shelter** (figs. 33 and 117).—The war along the western front has developed into essentially a siege operation on a large scale, and represents the necessity for the use of shelter under conditions in which opposing armies are about equally matched. In the firing trenches the men are sheltered in dugouts deep underground, each with room for from 3 to 8 men. Fifteen to 50 yards in the rear of the firing trenches are the cover trenches, which furnish shelter for at least two-thirds of the firing line and supports. The reserves in rear are furnished yet more elaborate shelters, with plenty of room for men to lie down and rest, and, when practicable, bathing facilities are provided.

166. **Machine guns.**—The general principles of their employment are:

(1) The personnel and matériel should be protected from fire as much as possible.

(2) In order that they may be available at the moment of attack, it is indispensable that they survive the bombardment. Their protection must therefore be specially provided for by employing all of the following means:

(*a*) Placing them under shelter.
(*b*) Making their emplacements invisible.
(*c*) Dispersing them laterally and arranging them in echelon.

(3) Casemates must be used only when they can not be seen by the enemy, such as on the reverse slope or in woods or villages.

(4) The great importance of making them invisible necessitates the construction of firing emplacements outside the shelters, but close enough so that the guns can be put in action with the least possible delay.

(5) The firing emplacement may be protected by a light roof with very slight height, or it may be entirely without overhead protection. The emplacement may consist simply of a pit in the open field situated in front or in rear of the parapet, and connected with the shelter by an underground passage. The machine gun should be placed in action at the last moment; it may be simply placed on the edge of the pit without any protection, but preferably should be covered by a light shield or a low parapet joining the natural slope of the ground with a gentle slope. The pit should be carefully hidden and will not usually be discovered by the enemy. Emplacements of this nature are frequently employed in rear of the firing line.

6. When the firing trench is situated on the reverse slope machine guns should be emplaced in concealed pits in front of the trench and connected with it by underground passages.

(7) The requirement of invisibility makes it necessary to conceal all the approaches to the firing emplacements by making them underground and to increase the number of emplacements so that it will not be necessary to fire daily from those to be used in case of an attack.

(8) The emplacement of too many machine guns in the first line is dangerous; in order to stop an attack they should be echeloned to the rear. In favorable terrain, flank fire should be provided to mow down the attacking lines as they push forward. Therefore the available machine guns should be distributed between the firing trench and the terrain in rear, with each emplacement prepared in a manner suitable to the terrain and object in view.

167. **Emplacements and shelters for trench weapons.**—In trench warfare batteries of light mortars and other trench weapons are generally situated between the cover and support trenches. Like machine-gun emplacements, they are of two types, viz, with and without overhead cover. Whenever overhead cover is used, if practicable, alternative emplacements without it should be constructed near by. The emplacements should be concealed as much as possible, and for this purpose the command should not be greater than that of the adjacent trench. The guns should be dispersed laterally and in depth as indicated for machine guns.

168. **Depots for material and ammunition.**—These consist of galleries of variable dimensions, opened in the walls of the trenches and approaches, and usually lined with timber, like mine casings. The entrance should be closed with a strong door. They are used to store water, rations, ammunition, grenades, pioneer tools, portable searchlights, field glasses, maps, range finders, periscopes, lighting pistols and rockets. Depots for engineer material are usually installed in the angles of the approaches. Depots for water, rations, tools, and sandbags are usually established about 20 yards to the right of the company command post. Depots for arms, ammunition, bombs, grenades, and rockets are about 20 yards to the left of the same post. An inventory of the material should be kept up to date at the company command post.

169. **Daily upkeep of approach and communicating trenches.**—The difficulties are to fix the responsibility for the upkeep of the several parts and to order only such work as can be done. An exact and measured plan of the approach and communicating trenches is here of inestimable value. The method by task work should be used, tasks being assigned to small squads, distant 100 to 300 feet from each other, and all beginning work at the same hour on the entire length of trench. When 25 men are put together at the beginning of a trench they fall over each other and never finish their job.

mand posts, telephone stations, first-aid stations, trench depots,
, the supply of drinking water, latrines, lavatories should
be constructed in short covered trenches at the angles in
oaches. For equipment, drinking water, rations, and lanterns
signposts, niches of various sizes are constructed in the

parapet or recesses, lined with timber, are constructed in the walls of the trenches.

170. **Maintenance.**—Order and sanitary conditions must be rigidly exacted in the trenches, or they will soon become untenable or very unhealthful.

The trenches after prolonged use deteriorate, not only from the fire of the enemy, but also from the effects of the weather. They must constantly be repaired. Walls which break down must be revetted. Firing banquettes must be constantly repaired with planks, fascines, or other revetting material. Damaged parapets must be repaired. Berms must be kept at proper width. Drainage pits must be watched carefully and kept cleaned out. It requires constant work to keep trenches clean and sanitary. Any commander who tolerates lack of work or poor work under any pretext is wanting in the first duty of a commanding officer.

When parts of trenches are captured steps must be taken immediately to clear them of insects which swarm in them and transmit disease germs, particularly typhus. Straw should be burned in the trenches and shelters, and all wood should be whitewashed.

171. **Shower baths.**—These should be installed in a deep shelter or in a cave shelter. A simple arrangement is to provide one or two kettles for heating water, tubs, or casks for storing water, placed about 9 feet above the ceiling of the shelter. The tubs or casks should be connected with a pipe fitted with sprinklers, properly spaced. There should be a grating on the floor, and the bottom of the approach should have a fairly steep slope toward a drainage pit.

172. **Water supply.**—This usually consists of several large casks filled by pipes if practicable, otherwise the water is carried to them. There should be an interval of at least 10 yards between casks to avoid crowding and mud puddles.

173. **Signposting the approach and communicating trenches.**—At all crossings two solid signboards must be set into the berm, beyond the reach of involuntary blows of passers-by. Their position is important. Whoever sets them must put himself in the position of both the passer-by coming from the front and the one coming from the rear and then arrange the signboards so that no one can mistake them.

Often the big approach trenches are named and marked only up to a parallel beyond which they are doubled or quadrupled by others which absorb them into their special system of notation. This is a mistake. The approach trench must keep its name up to the parallel of departure, because it forms an important known feature or avenue in the trench system and the terrain.

174. Besides the signposting a simple rule prevents confusion between an approach trench and all those connected with it. That is, wherever there is a crossing or a fork to keep the bottom of the principal approach trench at 12 to 16 inches below that of the offshoot trench. It is thus clear that if one takes a step up he is leaving the principal approach trench. In the same way at a right angle turn a few blows of a pick will form a small arc of a circle and suggest the continuity of the main trench. These small efforts will save many an error and much confusion.

175. It is desirable to have traffic in one direction only in an approach trench, so one set is built for bringing troops up from the rear and another generally parallel for evacuation or moving to the rear. Movement in the contrary direction should be allowed only by special order.

176. An approach trench should merely cross a parallel (such as a support trench) and should not use even a small portion of the parallel for the movement of men to the front or rear. The objections are that men may make a wrong turn, right or left, into the parallel, and that the presence of troops in the parallel will interfere greatly with the movement to front and rear. The rate of flow of the movement through an approach trench is that of its most difficult

point, for example, an underground passage, tunnel, or a hole full of [illegible] every effort should be made to improve these [illegible]

Everything that hinders movement in approach and communicating trenches must be rigidly suppressed. Shelters and niches must be so placed that they can not interfere with the use of the trenches as free corridors.

177. **Command posts.**—For every 100 to 150 yards of new trench constructed there should be a command post for the company or battalion commander, the brain center of the new organization of trench works thus created. These command posts may be the vital points of the future battlefield. They should be placed conveniently near the main communicating trench, and should be numerous enough for all uses during an action. Each command post must have a specific identifying letter or number, the series not to be repeated where there would be danger of confusion, so that when an officer comes to take possession he can immediately record his address without the least danger of mistake. These posts will be marked by big signboards and on the map or plan by a clearly legible conventional sign.

Command posts if located and marked as described will thus form definite spots in the terrain, known to every one and used as the origin of coordinates for indicating other nearby points. For this reason the necessary supplies that troops in the vicinity may need in an emergency should be collected at some point definitely located with reference to a command post. The command post of every captain should therefore have at 20 yards to the right a depot for water, food, and sandbags; at 20 yards to the left a water-tight shelter for cartridges, grenades, and rockets. When these are needed urgently by troops in front they can be found and furnished. This coordination of the supply depots with the command posts of the captains must be regulated and insisted upon by the higher commanders.

The command posts being thus important centers and not the mere shelter for the company commander, they must be uniformly and positively supplied with certain articles, as follows: A table, a water barrel, a lamp, oil and candles, a periscope, simple box or pigeonholes, a gas mask, an oiled cloth, and a curtain. All this material must be placed in the post when it is built and not distributed the day before an attack to the company commanders. In each command post there is a pad or book of printed forms for orders, requisitions for supplies, and other necessary papers.

The command posts may also be used advantageously as material depots where the supplies for the troops will be continually collected and inventoried.

178. **First-aid stations.**—These are connected with the cover or firing trench by a communicating or approach trench wide enough to carry a litter. They are constructed like other shelters. The walls are covered with straw or hurdle work, which must be frequently changed. They should be at least 8 by 12 feet in size. Two cots should be placed against one wall, and a bench for the wounded to sit on against the other.

179. **Kitchens.**—These should be constructed in shelters. The stovepipes should project somewhat above the top of the shelter to secure good draft. In addition, numerous ventilating holes must be made. The shelters should be large enough to accommodate the rolling kitchens. Small fires built of dry wood in the bottom of deep [illegible]s do not betray the position of the trenches.

[illegible] **avatories.**—These are improvised of tin or wood so as to [illegible] umber of basins in a row, with holes in the bottom, placed [illegible] ooden trough, which receives and carries off the water to [illegible] pit. There should be a grating for the men to stand on. [illegible] be constructed in a branch trench, covered if practicable. [illegible] he trench should have a decided slope for drainage.

MINING AND EXPLOSIVES.

181. **Military mining** will be here considered to include only the operations incident to forming communications or chambers completely underground; to placing in such chambers charges of explosives and to firing such charges.

Other uses of explosives in engineering operations are more commonly classed as **blasting** and will be considered under **demolitions.** Blasting also includes the use of explosives in forming the underground spaces in the process of mining.

Underground communications are classed according to their directions as **galleries,** which are horizontal or nearly so, and **shafts,** which are vertical or nearly so.

Galleries are classed according to their size as **great** or **grand galleries,** which are 6 feet high by 7 feet wide; **common galleries,** 6 by 3½ feet; **half galleries,** 4½ by 3 feet; **branches,** 3½ by 2½ feet; and **small branches,** 2½ by 2 feet. When the formation of the ground permits, earth augers may be used, forming **bores** or **drill holes.**

Shafts may be drill holes or wells, or may range in size from the smallest in which a man can work, say, 3 by 3 feet, to any size which may be required, seldom more than 6 by 10 feet.

The dimensions of galleries and shafts are determined by the use to be made of them, their length, and the minimum space in which men can work. If troops or guns are to be passed through galleries, they must be made large enough for that purpose. Grand and common galleries will usually meet these requirements. Galleries used only to reach the proper point to place the explosive are made of the size which is most rapidly driven and can be sufficiently ventilated. This is usually the half gallery, in which men can work without too much constraint, through which the excavated earth can be transported by efficient methods, and in which reasonable ventilation can be maintained by simple means.

Branches or small branches may be used when near the objective points. They are rapidly driven for short distances, 20 feet or so, but when longer the difficulties of digging, earth disposal, and ventilation become too great. When the soil permits the use of augers, bores will usually be employed for this purpose.

The quantity of explosive placed at any point is called a **charge.** The place prepared for the reception of the charge is called the **mine chamber** or simply the **chamber.**

182. **The primary requisites** of subterraneous excavations are **accuracy of direction, prevention of caving, ventilation, drainage,** and **lighting.**

The restricted space usually requires not only that men shall work in constrained positions, but also that special tools be provided of smaller size than those used for open earthwork. A special tool called the push pick, shown in figure 135, is very convenient in soft earth. Picks and shovels for mining are similar in form to standard tools, but are smaller, and have shorter handles.

183. **Accuracy of direction** may be secured in sufficient degree by refined application of methods described in Reconnaissance. The **principal characteristic** of underground surveying is the **absence of daylight.** All targets must be luminous, and readings of instruments may be made by artificial light. As a rule, the less light there is in the gallery, other than the target and reading lights, the better.

The best target is a light of medium strength behind a narrow slit, and is easily improvised. A convenient form is shown in figure 136. The slit is V-shaped in form and adjustable by rotating the two sides about their pivots, so that the maximum width can be adjusted to the intercept of the wire at various distances, as shown in figures 137 and 138. A sheet of white paper or cloth behind the light will enable the observer to work much faster.

In large galleries a transit may be used, and in smaller ones a plane table or prismatic compass. The box compass can not be sighted and read with sufficient accuracy for this work. Compass courses can not be relied upon, as the needle is subject to abnormal fluctuation when used underground. At each change of direction the back azimuth and azimuth must be carefully read and the angle between them used to determine the change. The light used for reading a compass should be nonmagnetic and nonelectric, or if not so, must be held in exactly the same position during both readings.

A ranging device may be improvised as shown in figure 138. The edges of the box should be straight and parallel to each other and to the line of sight. The box resting on a smooth board or paper nearly level is pointed at the back and forward targets in succession, a pencil being drawn along one edge in each position. The angle between the pencil lines is measured with a protractor.

The slope of an inclined gallery is maintained by the use of a **field level.** Many forms may be improvised by the use of a level tube or plumb line. A convenient form is shown in figure 139. The two pieces having been pivoted together, as shown, are given a series of suitable angles of inclination, and at each setting a small hole is bored through both pieces, forming two series of holes, as indicated. To reproduce any setting spread the pieces until the corresponding holes fall together and put a closely fitting pin through both. The longer piece is placed on the inclined line of the gallery, usually on two consecutive frames, for which its length is adapted. On the shorter piece may be placed an ordinary carpenter's or other level, or a level tube may be set in the piece itself if convenient.

The greatest accuracy need not be maintained during the construction of galleries though carelessness must be avoided. When the immediate vicinity of the chamber or other objective point is reached the entire line must be checked as accurately as possible, and the length and direction of the branch or drill hole necessary to reach the objective point must be determined. The digging having been substantially completed, the galleries may be kept clear of men to facilitate work when this final survey is made.

184. **The first step** in any mining operation will be to locate the objective point with respect to the point of departure by the best practicable measurements above the ground, preferably intersections with a transit from a carefully measured base. This position should be plotted on a good map. If no obstructions are suspected, a straight line from the point of departure to the objective should be adopted for the gallery and its length and azimuth determined. A profile of the ground along the line of the gallery permits determination of the proper slope or slopes.

The transfer of the azimuth underground will depend on whether the gallery starts from a shaft (fig. 143), from a reverse slope (fig. 140), or, if not very deep, from a level with a descending branch (fig. 141). In the second and third cases, which will be the rule in military mining, the azimuth may be established in the gallery by a transit or compass used in the ordinary way. In the case of a shaft, which will be the exception, the azimuth must be established *across* the top or mouth and transferred to the bottom by means of plumb lines (fig. 143). The plumb lines should be fine wires, the bobs true and heavy, suspended in water if necessary to steady them, and the marking should be done by scratches on the heads of nails or tacks. During construction the alignment may be kept by a line stretched along the gallery and the elevations by the field level.

Changes of direction, if necessary, are most conveniently measured in the gallery by means of a **bevel** made above ground to the proper angle (fig. 142). In checking, the angles should be determined ful geometrical construction in the gallery or measured with ment.

e an unexpected deviation is necessary, as to avoid an t may be made to suit the conditions found and afterwards nd plotted on the chart. The necessary change to be made after the obstacle is passed, in order to direct the gallery again on the objective, will be determined from the chart and the proper bevel made and sent into the gallery with instructions to make that change to right or left at a stated distance from the last angle.

185. **Gradients** are determined by the **field level.** Points at which changes of slopes are to be made must be determined from the chart and the necessary data sent in, showing the point where the change is to be made and designating both old and new slopes. In checking, gradients should be determined with clinometer or transit, sighting from one horizontal angle to the next, if it can be done, otherwise taking as few sights as possible.

186. **Prevention of caving** is accomplished by **linings.** In very firm soil it is sometimes practicable to drive small shafts and galleries short distances without lining them; but if they are to stand for any length of time there is always danger of their caving in, and especially so if the neighboring soil is shaken by the explosion of projectiles or mines. When it is considered safe to use them, unlined shafts should be elliptical in plan, and the roofs of the galleries should be pointed arches. **As a rule,** however, both shafts and galleries **should be lined.** Those which are permanent in their character, as the main galleries of the countermines of a permanent work, are lined with masonry. Galleries constructed during a siege are lined with wood. **Wooden linings** are of two general types, known as **cases,** and **frames and sheeting.**

Cases (fig. 144) are of plank, 6 to 9 inches wide and not less than 1½ inches thick, as a rule. They are formed as shown in the figure. The two pieces with tenons are called **stanchions** and are placed vertically. The top is called a **cap sill** and the bottom a **ground sill.**

In grand galleries the tenons at the top of the stanchions are usually shorter than the thickness of the cap sill, and those at the bottom, as well as the mortises in the ground sill, are omitted. The stanchions are kept from collapsing by blocks nailed to the ground sills. These blocks are 2 inches thick and wide enough (about 9 inches) to guide the wheels of a gun carriage and prevent the hub striking the stanchions (fig. 147).

In cases for smaller galleries also the tenons are sometimes omitted at the bottom of the stanchions, the mortises in the ground sills cut an inch or two deeper, and the stanchions kept from collapsing by keys driven in the mortises (fig. 146).

Frames and sheeting.—Frames are made of scantling, as shown in figures 148 and 149 for shafts, and 150 for galleries. Pieces of the latter are named as for cases. **Sheeting** is of plank, sawed to the desired length and beveled at one end. Sheeting should ordinarily be 1 foot longer than the distances c. to c. between frames. Frame distance is generally 4 feet and the length of sheeting 5 feet. Round stuff may be used for frames and also for sheeting, though the latter is not easy. The middle of each cap and ground sill, both in frames and cases, is marked by a saw cut or otherwise.

For galleries of moderate size, in good soil, lining with cases is more rapid and gives a smooth interior. Cases require uniform and fairly good lumber, which may not be obtainable. Frames and sheeting can be used for all sizes of galleries and in all soils and can be improvised from materials at hand.

The cases of branches and small branches are sometimes made very strong, with a view to resist rupture by the explosion of neighboring mines. Four-inch planks, or even thicker, have been used in certain circumstances.

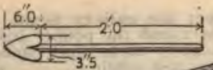


Fig. 135

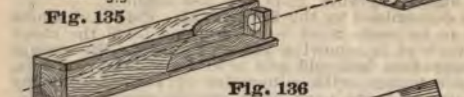


Fig. 136

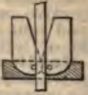


Fig. 137

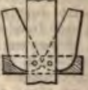


Fig. 138

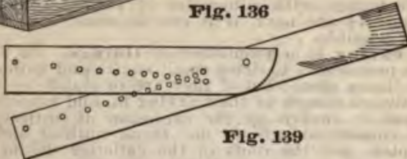


Fig. 139

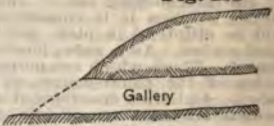


Fig. 140

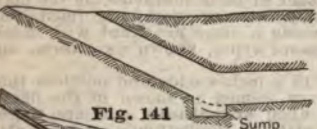


Fig. 141

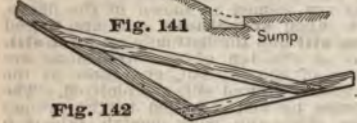


Fig. 142

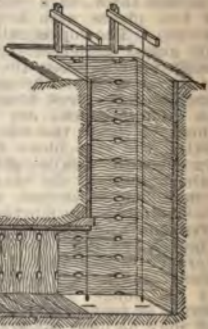


Fig. 143

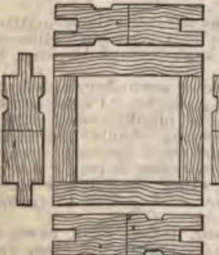


Fig. 144

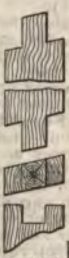


Fig. 145

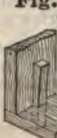


Fig. 146

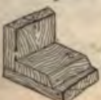


Fig. 147

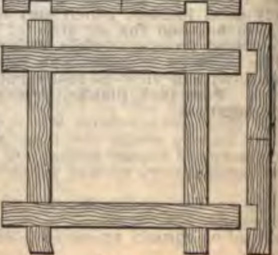


Fig. 149

187. The following table gives the **dimensions,** in inches, usually adopted for the pieces of **cases, frames,** and **sheeting,** for galleries of different sizes:

	Cases.			Frames and sheeting.			
	Ground sill.	Stanchion.	Cap sill.	Ground sill.	Stanchion.	Cap sill.	Sheeting.
	Ins.	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
Great galleries	3	4	5	6 x 4	6 x 6	6 x 9	2
Common galleries	2	2	2	6 x 3	6 x 6	6 x 8	1½
Half galleries	2	2	2	5 x 3	5 x 5	5 x 7	1½
Branches	1½ or 2	1½ or 2	1½ or 2	4 x 3	4 x 4	4 x 5	1 or 1½
Small branches	1 to 2	1 to 2	1 to 2	3 x 3	3 x 3	3 x 4	1

188. **In sinking a shaft** with **frames** and **sheeting,** the size and position having been fixed, the **top frame,** distinguished from the others by projections at each end of each piece (fig. 149) is laid down and staked in place, with the scores on the end pieces accurately in the desired azimuth. The excavation of the shaft is then begun, making it enough larger than the top frame to take the sheeting all around. Usually the first interval can be dug without driving the sheeting. It is undercut so that at the level of the second frame it will be larger in each direction than at the top by twice the thickness of the sheeting. Gauge rods cut to the length and width of the excavation and plainly marked at the middle points should be provided. The inconvenience of working under the top frame may be avoided by marking the sides carefully and digging the first interval before setting the top frame.

When the shaft is deep enough the second frame is put in place and nailed together; the notches in the ends of the side pieces turned upward and those of the end pieces downward. The top and second frame are connected by nailing to them four battens of proper length (two on each side) (fig. 151), which suspend the second from the top frame at the established interval. The second frame is placed vertically below the top frame by using the plumb line and the scores in the frames.

The sheeting is inserted outside the top frame, beveled end first, bevel outside, and pushed down until its top is flush with the top frame. The lower end of the sheeting is held out from the lower frame by suitable wedges, and the excavation of the second interval is commenced.

In ordinary soil the sides of the shaft will now require support. Sheeting is therefore introduced and pushed down as the excavation proceeds (fig. 152), the wedges previously placed being driven down as the sheeting is inserted.

If the pressure of the earth becomes great enough to spring the sheeting planks inward, an **auxiliary frame** is introduced. This is a frame similar to the shaft frames, but from 4 to 6 inches larger in outside dimensions (fig. 153). The sheeting rests directly against the outside of this frame, and is thus held out far enough to allow the third frame to be placed and the wedges to be inserted as before. The auxiliary frame is then removed and used in the next interval.

Successive frames are placed in the same manner (fig. 151) until the one directly over the gallery is reached. Care is taken to place this frame at exactly the right height, and the shaft is then continued to the required depth. A frame is placed at the bottom with its top at the level of the floor of the gallery and the sheeting is allowed to rest directly against the outside of this frame. When the soil will allow it, the sheeting is omitted wholly or in part over the portion of the shaft which is to form the gallery entrance.

If necessary the lower sections of sheeting may be supported by smaller frames placed inside the lower frame of the preceding sections or below them. The shaft thus decreases in size from top to bottom.

189. **Precautions.**—In sinking shafts especial care must be taken to make the excavation no larger than is required for placing the lining, since if a vacant space is left outside the lining the sides of the shaft may give way through its entire height and fall against the lining with a blow which will crush it in. *This has often been the cause of fatal accidents both in shafts and galleries.*

190. **Partly lined shafts**, i. e., those in which the sheeting planks are separated from each other by greater or less intervals, should only be used for small depths and when they are expected to stand for a very short time. They are a constant menace to the miners, owing to the danger of their caving in, and in a much greater degree to the probability of stones, etc., falling from the unprotected parts and seriously injuring or killing the men at the bottom.

191. **Driving a gallery with frames and sheeting.**—If from a shaft, the direction of the gallery has already been marked by the scores on the shaft frames; but it must be verified by plumb lines, and two small pickets driven on the line of its axis, which is located exactly by small nails, one driven in the head of each picket.

Two gauge rods are prepared, giving the extreme height and breadth of the excavation, i. e., the height of the frame plus two thicknesses of top sheeting, and the breadth of the frame plus four thicknesses of side sheeting. The middle of each gauge rod is also plainly marked.

A gallery frame is set up against the side of the shaft (fig. 151), its ground sill flush with the bottom frame of the shaft; or its stanchions may rest upon the shaft frame as a ground sill. This frame is carefully located and fastened in position with battens and braces. If the shaft sheeting on that side has been omitted, which can usually be done, the top gallery sheeting is started on top of the cap sill and driven until held in place by the earth. It is given the proper upward pitch by a scantling laid across the outer ends and held down by fastening to or under the shaft frame. The side sheeting is started in the same way against the outer faces of the stanchions and given an outward slant by bracing the outer ends slightly away from the sides of the shaft. Earth is now excavated and the sheeting advanced all around, keeping the front ends in solid earth far enough to hold them steady.

In this way the gallery is advanced one gallery interval, usually about 4 feet, when a second frame is placed. Its position is verified by the score marks; for direction, by a line; for grade, by a spirit, mason's, or field level, and for verticality, by a plumb line. It is then secured in place by nailing battens to it and the preceding frame. Wedges are inserted between the frame and the sheeting and the gallery is continued by the same methods. When the sheeting is advanced only by hard driving the frames are slightly inclined to the rear at first and are afterwards driven forward until vertical.

192. If, while advancing the sheeting, the pressure upon it becomes so great as to spring it, a **false frame** (fig. 154) must be used.

This consists of a cap sill, ground sill, and two stanchions, connected by mortises and tenons. The stanchions have tenons and the sills mortises at each end. The cap sill is usually rounded on top and, for facility in setting up and removing, its mortises are longer than the width of the tenons. The latter are held in place by wedges when the frame is in position (fig. 155). The false frame is usually made of the same height as the common frames and, when *side sheeting* is used, wider by twice the thickness of this sheeting.

When side sheeting is not used, its outside width may be equal to the clear width of the gallery.

In using the frame (fig. 154) the ground sill is first placed accurately in position at a half interval in advance, the stanchions are set up, and the cap sill placed upon them and wedged. The whole frame is then raised about 2 inches by folding wedges placed under each end of the ground sill, and is secured by battens. The sheeting will now rest directly upon the cap sill and stanchions and have enough inclination to clear the next frame by its own thickness, as is required. The next frame is then set up, the wedges driven under the sheeting, and the false frame removed, which is easily done, owing to its construction.

If the gallery is not started from a shaft, a steep working face must be obtained and the first frame set up and braced, in correct position with respect to the center line marked on the ground. The subsequent operations are as above described, except that means must be provided to hold the rear ends of sheeting to give them the necessary upward and outward slant, or else a false frame used.

If it has been necessary in sinking the shaft to drive the sheeting on the side from which the gallery is to be broken out, the gallery frame is set as before and the sheeting behind it driven down until it barely engages the bottom edge of the cap sill of the gallery frame. The top gallery sheeting is then inserted and partly driven as before. The shaft sheeting outside the gallery stanchions is then cut away and the side gallery sheeting started. The middle plank of the shaft sheeting is prized down with a bar engaged under the cap sill until free at the top, when it is pulled outward and removed. Excavation proceeds through the gap thus made, and as the other planks come free they are removed. If the earth runs too free at any stage of the operation it can be checked by short horizontal stop plank placed against or inside the sheeting or inside the gallery frame after all sheeting has been removed.

193. To continue the gallery in such soil a **shield** (fig. 156) may be used to prevent the earth in front and above from caving into the gallery. When the excavation at top of gallery has advanced as far as it is safe to go without causing the caving to extend beyond the top sheeting, a piece of plank a foot wide and in length equal to the width of the gallery is placed directly under the top sheeting and against the face of the excavation and is held in place by braces at its ends secured to the gallery lining. The earth is excavated until a second plank of the shield can be placed in the same way as before under the first one. This is continued until the entire face is covered. The top and side sheeting are then driven forward and the top plank of the shield is removed and replaced in advance, after which each plank is removed and replaced in succession, as above described.

194. **Partly lined galleries.**—In very firm soil side sheeting may be omitted entirely, and in that less firm the side planks need not be in contact. When the side sheeting is omitted the width of excavation may be reduced to the clear width of the gallery and the stanchions be let into the side wall flush with its surface. In this case the ground sills are frequently omitted, the stanchions resting upon wooden blocks, stones, or directly upon the earth.

To save material, the planks of the top sheeting are sometimes more or less separated also. This can only be recommended when rapid and temporary work is required with limited materials, and in these cases the earth between the planks should be supported by packing of sticks, brush, etc.

195. **Inclined galleries.**—If the gallery, instead of being horizontal, is **ascending** (fig. 157) or **descending** (fig. 158), the proper slope is obtained by the use of a field level or a mason's level properly marked or set for the slope.

Position of frames.—In driving **descending galleries** better progress will be made and less material used if the frames are set

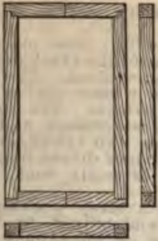


Fig. 150

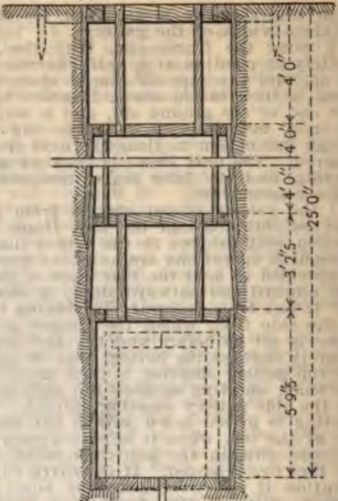


Fig. 151

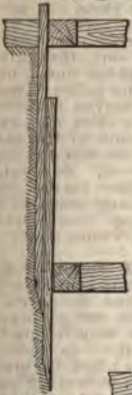


Fig. 152

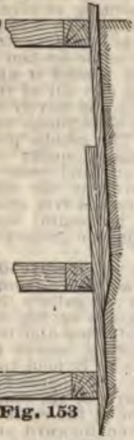


Fig. 153

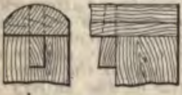


Fig. 155

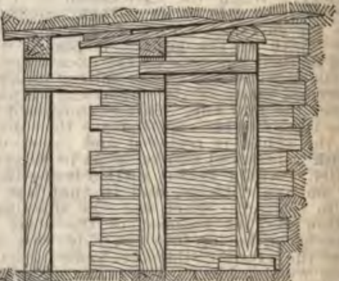


Fig. 154

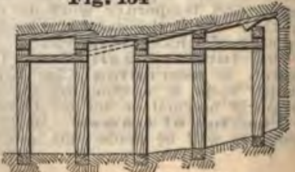


Fig. 157

at right angles to the axis of the gallery (fig. 158), and this is the usual custom. In driving **ascending galleries** this is impracticable and the frames are set vertically (fig. 157). In all other respects inclined galleries are driven in the same manner as horizontal ones.

196. **Change of slope.**—To pass from a horizontal to an ascending gallery (fig. 157) it is only necessary to give the top sheeting the proper angle by holding down its back end with a piece of scantling placed across the gallery for that purpose; and, to give the side sheeting the proper inclination, cutting trenches in the bottom of the gallery for the lower pieces if necessary.

In passing from a horizontal to a descending gallery (fig. 158) the roof may be carried forward horizontally, and the floor given the desired pitch by increasing the height of the consecutive frames, until enough headroom is obtained to allow the top sheeting for the descending gallery to be inserted at the proper height and in the new direction. The frame at this point is made with a cap sill (upon which the sheeting rests directly), and a second crosspiece below it, serving as a cap sill for the descending gallery. From this point forward the frames may be set perpendicular to the axis of the gallery, as previously stated.

If the descending gallery is very steep and the horizontal pressure of the soil great, it may be necessary to strengthen the stanchions of the last two or three vertical frames by crosspieces near their upper ends.

197. **In changing direction horizontally** with frames and sheeting, if the soil will stand for a distance of one frame interval, or even less, it is only necessary to place one or more frames at an angle until the necessary change is secured. The sheeting on the outside is placed by running the forward end past the frame and then inserting the rear end behind the last bay of sheeting.

If the sides require constant support, the outer one may be continued in the old direction until the wedge left is thick enough to permit the sheeting to be driven in the new direction. A short bay may be put in to reduce the amount of work to be done (fig. 161). Frames with extra-long caps and sills are required, and the last one used is given an extra stanchion on the outside to take the sheeting in the new direction.

For abrupt changes of direction in large galleries it is customary to drive in the original direction entirely past the turning point and then break out a gallery in the new direction. A gallery starting out from the side of another is called a **return,** and is **rectangular** or **oblique,** according to the angle made by its **axis** with that of the original gallery, which is called the **gallery of departure.**

That the return may be broken out, the interval between the frames of the gallery of departure at this point must be such as to admit between the stanchions a frame and the side sheeting of the return (fig. 165). This part of the gallery of departure is called a **landing** and its floor is made horizontal.

If the return is oblique (fig. 166), its width measured along the gallery of departure will be determined by an oblique section, and may be so great that the strength of the lining of the gallery of departure will not allow the necessary length of landing. In this case a short rectangular return is first broken out from the side of the gallery of departure and the new gallery is broken out from the side of this return (fig. 167). The latter method diminishes the length of the landing when the change of direction is less than 45°.

The floor of a return is started at the level of the floor of its landing. In firm soils which will stand for a short time without support the first frame may be set up entirely outside the gallery of departure (figs. 166 and 167) and may be of the same height in clear as this gallery. When the soil is bad, however, and side sheeting is required in the gallery of departure, the first frame of the return must be set up against this sheeting in the interval between th stanchions of the landing (fig. 165). This makes the clear height of the return at this frame less than that of the gallery of departure by a little more than the thickness of the sheeting. When the first frame of the return is set against the sheeting of the gallery of departure it may be pulled or cut away to permit excavation, beginning in either case with the top plank.

The first frame of an oblique return should be so set that the sides of the stanchions will be parallel to the side walls of the return, thus giving a good bearing to the side sheeting.

In very bad soil the first few frames of a return must be firmly braced, to resist the backward thrust of the earth, by battens connecting them together and by struts across the gallery of departure. The latter are removed when the return is sufficiently advanced.

198. **In sinking a shaft with cases** (fig. 159) a case of the required size is put together and accurately placed upon the site of the shaft, whose dimensions are marked upon the ground outside it. The case is then removed and the earth excavated to the depth of the case, which is placed in the excavation with its top flush with the surface of the ground. Its position is carefully verified and it is secured in position by packing earth around it. The excavation is then continued for the depth of another case, which is put in place as follows:

One end piece is placed in position, the tenons of the two sides are inserted in the mortises at its ends, and the side pieces are pushed back into position; a pocket-shaped excavation is made with a push pick beyond the end of one of the side pieces and running back 3 or 4 inches into the side wall; the remaining end piece is inserted in this cavity far enough to allow the mortise at its other end to slip over its corresponding tenon; it is then drawn back and the tenons at both ends fitted into their mortises. The notches cut in the sides of the pieces allow them to be easily handled.

The next case is placed in the same way, care being taken not to excavate two consecutive pockets at the same corner. It is well to fill up these pockets by stuffing in sods from below before placing the next case.

When the sides of the case are tenoned at one end only and secured by wedges at the other they are easily placed in position without cutting out behind them.

Upon reaching the level of the top of the gallery, the pieces on the gallery side of the shaft are omitted if the ground is firm, but if it needs support these pieces are put in place and secured by cleats or braces, but the tenons are not inserted in the mortises. In firm soil the cases may be placed at intervals (fig. 160).

199. **Driving a gallery with cases.**—This is practicable only when the soil is somewhat firm. In breaking out from a shaft, a frame is first placed inside the shaft to support the ends of the shaft cases resting against the pieces which are to be removed. The latter pieces are then taken out and grooves are cut in the earth for the ground sill, stanchions, and cap sill of the gallery, and these are put in place in a manner entirely analogous to that described for sinking a shaft. This case is set flush with the inside of the shaft and supports the side pieces, whose tenons rest upon its stanchions. The projecting earth is then cut away and grooves are cut for the next case, which is placed in position and the excavation continued as before (fig. 162).

If the gallery is not started from a shaft, a vertical face is obtained and the cases are placed as above described.

When the earth shows a tendency to cave, which it frequently will in great galleries, the cap sill must be put in position and supported while the miner excavates the grooves for the ground sill and stanchions, for which purpose two **crutches** are used. **A crutch** (fig. 163) consists of an upright piece of timber carrying a crosspiece, whose length is equal to the width of two cases. The upright *piece rests* upon the ground sill of the cases already placed and is

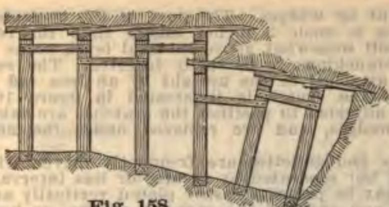


Fig. 158

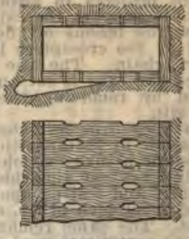


Fig. 159

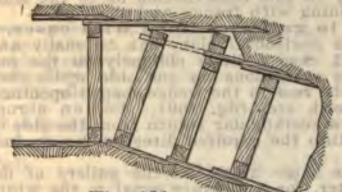


Fig. 161

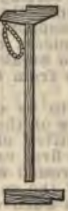


Fig. 163

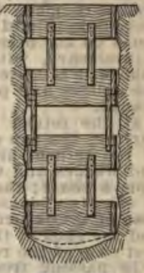


Fig. 160

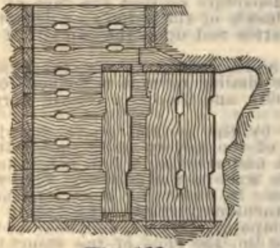


Fig. 162

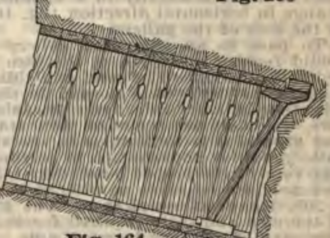


Fig. 164

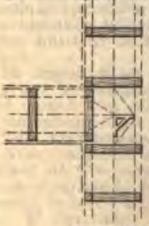


Fig. 165

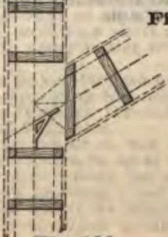


Fig. 166

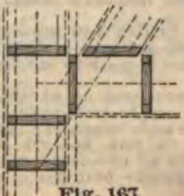


Fig. 167

raised to the proper height by wedges. The part of the crosspiece which projects in advance is made 2 inches higher than the rear part, to support the cap sill somewhat above its final level, so as to allow the tenons of the stanchions to be easily inserted. The rear part of the crosspiece is attached to the upright by an iron rod or short chain. The use of the crutch is illustrated in figure 164. When the case is set and adjusted to position the crutches are taken down by removing the wedges, and are replaced under the next cap sill.

In very firm soil shafts and galleries are frequently driven with cases not in juxtaposition, but separated by greater or less intervals. Pieces of planks (which may be parts of cases) placed vertically and resting against the sides and ends of the cases in shafts, or horizontally and resting upon the cap sills in galleries and somewhat separated from each other, may be used to support the earth between the cases. The same remarks apply to this construction as to the similar one sometimes used when mining with frames and sheeting.

200. **Change of direction in galleries lined with cases.**—Slight changes in direction in a horizontal plane can be easily and gradually made by setting each case a little obliquely to the one preceding it and separating the stanchions on one side while they touch on the other, supporting the roof in the wedge-shaped openings, if necessary, with pieces of wood, etc. (fig. 169). For an abrupt change it is better to break out a rectangular return from the side of the gallery and pass from this into the required direction by gradual change.

If the return is to be of the same height as the gallery of departure, the cap sills of the latter, for a distance equal to the width of the return, are lifted off the tenons of the stanchions by struts and wedges and the first case of the return is set as in breaking out from a shaft; the ground sill is, however, narrowed by the thickness of the stanchions of the gallery of departure so that the face of the case of the return is flush with the inside of the gallery of departure and the ends of the cap sills of the latter rest upon the cap sill of the first case of the return.

In passing from a horizontal to a descending gallery the change may be made gradually in a manner similar to that described for a change in horizontal direction (fig. 169), and the cases remain normal to the axis of the gallery.

To pass to an ascending gallery by the method above described would require the earth at the face of the gallery to be undercut in order to introduce the case, and this undercutting would continue so long as the cases were normal to the axis of the gallery. This construction is, as a rule, impracticable. In ascending galleries, therefore, the cases are set with their stanchions vertical, while their cap and ground sills form steps in the slope of the roof and floor of the gallery or, for convenience in settihg up, the ends of the stanchions may receive the proper bevel (fig. 155), while the sides of the tenons and mortises are made parallel to the sides of the stanchions.

201. **Rate of working.**—The following table gives an estimate of the men and tools required for shafts and galleries, with the probable rate of advance in good soil.

Kind of gallery, etc.	Men.		Tools.														
	N. C. officers.	Miners.	Picks.	Miner's picks.	Push picks.	Shovels.	Miner's shovels.	Miner's truck.	Field levels.	Measuring rod, 6'.	Tracing line.	Mauls or sledges.	Canvas buckets.	Rope ladder.	Wheelbarrows.	Miner's bellows.	Progress, ins. per hour.
Great gallery or blind gallery	1	[1] 12	4	2	2	8	...	....	1	1	1	1	...	...	4	...	12
Common gallery	1	4	...	1	1	2	1	1	1	1	1	1	...	...	...	1	12
Half gallery	1	[2] 4	...	1	1	2	1	1	1	1	1	1	...	...	...	1	16
Branch gallery	1	[2] 4	...	1	1	2	1	1	1	1	1	1	...	...	...	1	24
Small branch	1	3	...	1	1	...	2	[3] 1	([4])	1	1	1	...	...	...	1	30 to 36
Shaft	1	[5] 4	...	1	1	2	1	....	1	1	1	1	1	1	...	...	18 24

[1] Four of these may be unskilled laborers.

[2] Number required at commencement of gallery. Beyond 4 feet add one man, and one additional for every 20 feet of gallery.

[3] Instead of a truck a canvas bag may be used. A large hoe or drag may be used to draw back the earth from the face of the gallery.

[4] One mason's level.

[5] These numbers are for small shafts of about 2 by 4 feet; large shafts require a larger force. They advance at about the same rate as galleries of equal cross section.

202. **Ventilation.**—A gallery can not be driven more than 60 feet without artificial ventilation. The only possible way of ventilating a gallery with a single opening is to force fresh air into the working breast, which may be done through a duct of wood or metal, or through a canvas or other hose. **A pressure blower,** worked by hand or power, is among the essential items of a mining equipment. For excavations of moderate extent a portable forge will form a convenient ventilating device. If a gallery passes under surface cover a drill hole made through the roof and breaking the surface under protection of the cover may be used to promote ventilation.

In a **system of galleries,** having two or more outlets, air may be exhausted from one and drawn in through the other. Screens or doors may be arranged to compel the desired distribution of fresh air. Vacuum operation will never be so satisfactory as plenum. If there is considerable difference of level, as a shaft or rapidly ascending gallery, a fire built at or near the upper outlet will create a current throughout.

In urgent cases a man may enter and even work in a gallery which can not be ventilated by providing him with a mask covering the nose and mouth and supplying fresh air through a hose or from a reservoir of compressed air carried with him.

203. **Drainage.**—Much water is not likely to be encountered in military mining, but what there is must be taken care of, or it will collect at the lowest point and flood the mine. If water shows itself or is suspected, dead-level galleries must be avoided, and all slopes should fall toward a point or points where the water can be disposed of. If the mine has a level outlet nothing is required except to so

regulate the slopes that all water will run to the mouth. If the mine is entered by a shaft, a pit or sump must be formed at the bottom into which water can collect, and from which it can be raised to the surface by pumping or bailing. A slope of 1 per cent will usually suffice for drainage if the floor of the gallery is sloped laterally and a fairly smooth gutter formed along one side.

If an interior low point can not be avoided a sump must be made there and the water carried out in buckets or forced out with a pump. For low lifts, 20 feet or less, a very efficient form of hand pump for drainage purposes is shown in figure 170. A very good pump may be made as shown in figure 171. The only materials required are wood, leather, cotton cord, rivets, tacks, and nails. This pump will lift several feet without difficulty in addition to the usual suction. It requires copious priming unless the sucker can be made to reach the water at the lowest point of its strike. It is usually worked with a spring pole (fig. 172).

204. **Mining illumination.**—Owing to the restricted dimensions of the galleries, ordinary lamps can not be used without the atmosphere becoming vitiated. During the day, as far as possible, solar light is used, deflected by mirrors or by panels whitened with lime. At night strong reflector lamps are placed outside the gallery. Electric light renders great service, especially at the head of the gallery. The mine head is lighted by means of incandescent lamps led by a dynamo in the approach galleries. The conducting wires, protected by troughs, are buried in the bottom of the trench. Numbers of small hand flashlights are found valuable for personal use by the soldiers.

205. **The mine chamber** should be nearly cubical or a cylinder with length about equal to diameter. If it is to stand for some time before loading, or if of large size, its sides and top must be supported by a lining. The chamber is frequently no more than so much of the end of a gallery, branch, or drill hole as is necessary to contain the charge.

Figures 173 and 174 show typical forms of earth augers, the former used by ramming and the latter by turning. Each must be withdrawn when full to dispose of the earth.

206. **A military explosive for demolitions** should be—

1. Not too sensitive to shock or friction.
2. Of a high velocity of detonation.
3. Of high power.
4. Of high density.
5. Stable in character.
6. Not too difficult of detonation.
7. Unaffected by changes of temperature and moisture.
8. Convenient in form for packing and loading.
9. Obtainable in large quantities in the United States.

The authorized explosive, Triton, meets the above standard more nearly than any other explosive known. It must be recognized, however, that there are many other explosives made and used in this country, of almost equal value for general military uses and of superior value for some special purposes. The engineer reconnaissance of any locality must show the commercial explosives at hand, and the officer executing demolitions must use these explosives whenever time permits their collection or when the authorized explosive is lacking. The use of other explosives in this manner also saves the valuable triton for use where the maximum speed and certainty of execution is demanded. Consequently, a knowledge must be possessed of the nature and properties of the commercial explosives commonly used in the United States.

207. **Triton—Nature.**—Triton (Trinitrotoluene) is produced in form of crystals of a light yellow color. It melts at 80° C.
crystals, compressed to a density of 1.48, are issued in two
the triton block, weighing one-half pound, and **the triton**
weighing 0.4 of a pound. Each form of triton is issued copper-
and each has a cylindrical hole to receive the detonating cap
in the block or stick). This cap hole is closed with a cork

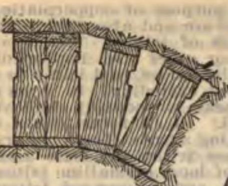


Fig. 169

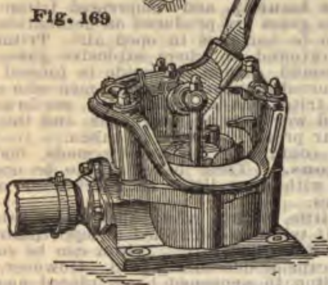


Fig. 170

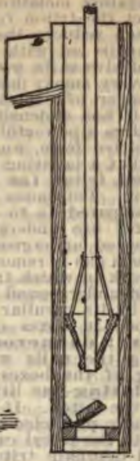


Fig. 171

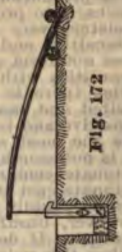


Fig. 172

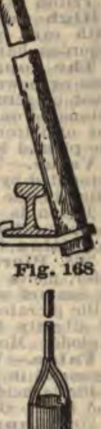


Fig. 168

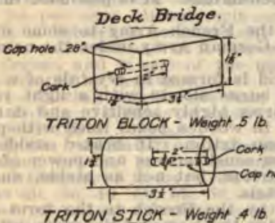


Fig. 175

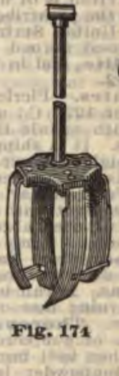


Fig. 174

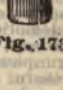


Fig. 173

Fig. 177

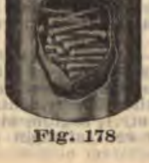


Fig. 178

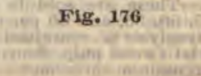


Fig. 176

as a precaution against moisture. The purpose of copperplating the blocks is to protect the triton from moisture and also from abrasion. Moisture very much reduces the strength of triton. Triton is very insensitive and can be cut with a knife or other steel implement. It does not form explosive salts with metallic oxides, and burns in small quantities with a very smoky flame without exploding. In large quantities there is danger of explosion if heat is suddenly applied. If melted and cast, it has a density of 1.6. In all forms triton is insensitive and requires a powerful detonating agent. The loose crystals are the most sensitive form, and the cast triton the least sensitive. It is noteworthy that a boosting charge of loose crystalline triton will detonate compressed triton **(as issued)**, and compressed triton will detonate cast triton. Poisonous gases are produced on detonation but are so rapidly dissipated as to be harmless in open air. Triton is, however, unsafe for use underground or where explosive gases are present. If detonated underground, carbon monoxide is formed and unless this poisonous gas is removed by ventilation, the men who enter an underground work in which triton has been detonated, are in grave danger. Its use in underground workings is inadvisable, and the precautions required by its peculiar properties must be taken.

Triton is shipped in boxes containing about 50 pounds, marked **"High explosive; dangerous."** These boxes are to be opened with care, pulling the nails with very little hammering or other vigorous handling of the boxes.

The copperplating has little, if any, effect upon the sensitiveness or power of the triton. If triton is furnished uncopperplated it must be scrupulously protected from moisture. Triton can be surely detonated only with the tetryl caps or detonating cord. However, one box of triton will detonate triton in unopened boxes placed against the primed box.

Value.—Triton is of high power, safe to handle, and can be surely detonated by the prescribed detonators. It is produced in large quantities in the United States.

Triton is used abroad in the French Army to some extent under the name **Tolite,** and in the German Army under the name **Sprengmunition 02.**

208. **Picrates.**—Picric acid is formed in crystals of a light-yellow color, melts at 122° C., and burns slowly with a light yellow flame. In contact with metals it forms highly sensitive and dangerous metallic picrates. It is shipped in wooden boxes lined with paper. It is of slightly higher power than triton. If heated suddenly it will explode. Moisture reduces the sensitiveness and power of picric acid.

Value.—Very similar to triton, but not as stable, and also dangerous if in contact with metals.

Picric acid is used abroad by the French in the form of Melinite, and in the German Army under the name of Sprengmunition 88.

209. **Gunpowder—Nature.**—This explosive, formed of a mixture of saltpeter, sulphur, and charcoal, is still of some military value for demolitions. It can be ignited by the mere application of a flame, as from a burning fuse or miner's squib. Water destroys the power of gunpowder. **Thorough tamping** is an absolute necessity for successful use of gunpowder in mines or demolitions. The power of gunpowder when well tamped is about one-third that of triton.

Value.—Gunpowder is still produced and used in considerable quantities in this country and is of considerable military use in land mines or other locations where thorough tamping is possible. The extensively used commercial English bobbinite is essentially a gunpowder.

210. **Nitroglycerin explosives—(a) Straight dynamites—Nature.**—These are sold in the United States as 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 per cent dynamites, according to the proportion of nitroglycerin contained. The other constituents are combustible material (wood pulp, flour, sulphur, etc.), sodium nitrate, and calcium *or magnesium* carbonate. Fifty per cent straight dynamite is equal

in power to **triton** weight for weight. Dynamite is furnished in sticks, wrapped in paper, of about 0.5 of a pound each. The sticks are packed in wooden boxes of two sizes containing, respectively, 25 and 50 pounds. Forty per cent dynamite is the grade most frequently encountered. The higher grades are exceptional.

Direct contact with water brings about separation of the nitroglycerin, and this constitutes a source of danger when the explosive is used in wet places. Its liability to freeze is another source of danger. Very strong detonators are required to explode it when frozen, and though in this condition it is fairly insensitive to a blow, breaking or crushing are distinctly dangerous operations. Thawing must be conducted with great care in a specially constructed double boiler provided with a jacket for hot water (fig. 178). Should exudation of nitroglycerin take place during thawing, this will introduce an element of danger in ramming.

During storage it must be protected from dampness and from heat; even sunlight must be avoided.

Value.—Dynamites are of high power and are readily obtainable. They are sensitive to shock, deteriorate in storage, and freeze at about 40° F.

(b) **Low freezing dynamites—Nature.**—Similar to straight dynamites, except not frozen at temperatures above 35° F. Sold in the United States as 30, 35, 40, 45, 50, 55, and 60 per cent. These percentages represent the proportion of nitroglycerin plus nitrosubstitution compound. The other ingredients are as noted for straight dynamite. The exact freezing point of these dynamites can not be exactly stated. In practice they have seldom been known to freeze above 0° F., and in special tests have remained unfrozen at temperatures as low as minus 40° F.

Value.—Similar to straight dynamites, with added value due to low freezing properties.

(c) **Blasting gelatin—Nature.**—Blasting gelatin is composed of 90 to 93 per cent nitroglycerin and 7 to 10 per cent collodion cotton. It is furnished commercially in a jellylike mass, packed in metal-lined wooden boxes. It is less sensitive than straight dynamite, liable to freeze, and is one of the most powerful explosives known. It is not affected by moisture.

Value.—Blasting gelatin has been largely replaced by the gelatin dynamite, but is a reliable explosive of very high power, about 2.1 times as powerful as triton.

(d) **Gelatin dynamite—Nature.**—This explosive is formed from blasting gelatin by the use of an absorbent to solidify the gelatin and thus make it more convenient for use. It is sold in this country as 30, 35, 40, 50, 55, 60, and 70 per cent gelatin dynamite. The actual percentage of nitroglycerin in each of these dynamites is about **10 per cent less** than the nominal quantity given. The other ingredients are nitrocellulose, sodium nitrate, combustible material (sulphur, flour, wood pulp, etc.), and calcium carbonate. Gelatin dynamites are of about 10 per cent less power, weight for weight, than straight dynamite of the same nominal percentage. Sixty per cent gelatin dynamite is equal to triton in power, weight for weight. Freezing of gelatin dynamite is a fault as in all other nitroglycerin explosives. It is, however, unaffected by water and is the most useful of the commercial dynamites, especially adapted for use in tunnel driving.

Value.—Gelatin dynamite is comparatively stable, adapted to work under water, is of high power, and is used in great quantities in this country.

(e) **Ammonia dynamite—Nature.**—This dynamite is sold in five grades in this country—30, 35, 40, 50, and 60 per cent. The nitroglycerin plus the ammonium nitrate in each grade varies slightly from the percentage given except for the 30 per cent grade. For the 60 per cent grade the variation amounts to about plus 5 per cent. The other ingredients are sodium nitrate, calcium carbonate, and combustible material.

Ammonia dynamites, compared with other dynamites, have the disadvantage of taking up moisture very readily, because ammonium nitrate is deliquescent, and care should be observed when they are stored or used in wet places.

Value.—Ammonia dynamites are distinctly superior to other dynamites only for use underground in the presence of explosive gases. Their use and storage where exposed to moisture tends to destroy their power. They are used extensively in coal mining in the United States. The low freezing ammonia dynamites are of great importance at the present time. The high price of glycerin has led to the use of this class of dynamite wherever water is not encountered.

(f) **Explosives for use in coal mines or elsewhere in the presence of pit gases (commercially known as permissible explosives)—Nature.**—These explosives, forming a long list, are those whose length, detonation, and temperature of flame accompanying detonation will not ignite mixtures of pit gas and air. Even for those listed there is a **charge limit** above which detonation is unsafe. The ammonia dynamites are included in these explosives, as well as other dynamites of low nitroglycerin percentage. The ammonia nitrates and other explosives are also included in this class. It is notable that **gunpowder, triton, picric acid, blasting gelatin, gelatin dynamite, and guncotton** are **not** suitable for such use. The name "permissible explosive" has very little military significance.

Value.—The great extent of the use of this group of explosives makes them of military value.

Ammonium nitrate explosives.—This class of explosives, developed to some extent prior to the present war, has come to the fore as a general military explosive. Of the numerous varieties of this class the most common ones contain 70 to 95 per cent ammonium nitrate, with the addition of combustible material, such as resin, meal, or naphthalene. **Ammonal** is a special type of this class, formed by a mixture of ammonium nitrate, aluminum, and a small percentage of trinitrotoluol. All of these explosives are very deliquescent and insensitive to shock.

Value.—The economic conditions created by the present war have so raised the prices of glycerin and toluol that this class of explosives is coming rapidly into prominence. An ammonium nitrate explosive is being used as a bursting charge for projectiles by both groups of combatants in the present war. It is notable that the only point of inferiority of selected types of this group for military use is their sensitiveness to moisture.

211. **Chlorate explosives—Nature.**—This group of explosives, consisting of a mixture of a metallic chlorate (sodium or potassium) with a hydrocarbon oil, are in most forms sensitive to shock and dangerous in use and storage. Cheddites in which castor oil is used is the most common form, is not highly sensitive to shock or friction, but has the disadvantage of easily becoming hard, and is then not completely detonated.

Sprengel explosives are chlorate explosives rendered reasonably safe by adopting the device of Sprengel and issuing the chlorate separately from the combustible matter. The potassium chlorate is made up into porous cartridges, and a liquid combustible is used; the former is dipped into the latter just before use.

Rack-a-rock, which has been used very extensively in America, consists of cartridges of chlorate of potash, which are dipped just before use into a combustible oil. For this purpose nitrobenzene is used, or "dead oil," which consists chiefly of hydrocarbons from coal tar, or a mixture of the two. The chlorate cartridges are inclosed in small bags of cotton; before use these are placed in a wire basket suspended from a spring balance and dipped into a pail con[illegible]ining the liquid, until a quarter to a third of the weight of the [illegible]rate has been taken up. The chlorate sometimes contains an [illegible]tion of a few per cent of iron oxide.

The objection has been raised to Sprengel explosives of this sort that the impregnation is not uniform, and the results obtained are consequently unreliable.

Value.—These explosives of the Sprengel type are of some military value, but have serious disadvantages, as noted, and in addition require considerable time to impregnate the chlorate properly before use.

212. **Guncotton—Nature.**—This explosive, manufactured by the nitration of cotton waste, is either molded in small cylinders or further compressed for use in military demolitions into blocks or cylinders of a density of from 1.05 to 1.2. Guncotton must be kept moist and is then highly insensitive. It requires a priming charge of dry guncotton for detonation. It is about 1.2 times as powerful as triton, weight for weight.

Value.—Guncotton is of high power, easily obtainable, but the necessity of using a priming charge of dry guncotton and its low density are disadvantages. It is used abroad to some extent as a military explosive for demolitions.

213. **Smokeless powder—Nature.**—This explosive, used so commonly as a propellant for projectiles, is liable to deteriorate in storage, and in storage must be guarded from ignition. It is difficult to detonate and, as it has a low velocity of detonation, must be thoroughly tamped for successful use as a demolition agent. It has about 1.2 times the power of triton.

Value.—The large production of this powder in the United States may call for its use in emergencies. The same instructions given for **gunpowder** apply to smokeless powder. It can only be used effectively where thorough tamping is possible, as in land mines, etc.

214. **The formula** given hereafter for triton in each case gives the number of **one-half pound** triton blocks required. To obtain the **pounds** of the following explosives to do the same work, multiply **N (the number of one-half pound triton blocks)** by **L** as given.

Explosive.	L.
Picric acid	0.50
Gun powder (if well tamped)	1.80
Straight dynamites:	
15 per cent	.84
20 per cent	.78
25 per cent	.74
30 per cent	.68
35 per cent	.62
40 per cent	.58
45 per cent	.54
50 per cent	.50
55 per cent	.48
60 per cent	.45
Low-freezing dynamites (same as Straight dynamites).	
Blasting gelatin	.25
Gelatin dynamite:	
30 per cent	.74
35 per cent	.70
40 per cent	.66
50 per cent	.60
55 per cent	.56
60 per cent	.52
70 per cent	.48
Ammonia dynamites (same as gelatin dynamites).	
Cholrates:	
Rack-a-rock	.78
Guncotton	.41
Smokeless powder (if well tamped)	.43

(b) **Precautions to be taken in the care and use of explosives.**—(1) Triton must be protected from direct artillery fire, as a burst of shell within a mass of triton will detonate it. Moisture must be kept away from triton. Ordinary shocks from usage or the fall of small loads of triton is without danger. In use **thorough** tamping is necessary to get full effect from triton as well as **all** other explosives. Only the **Tetryl cap** or **detonating cord** will surely detonate triton. A boosting charge of powdered triton around a powerful commercial cap will usually detonate triton.

(2) Picric acid must be protected as noted for triton and must also be kept from contact with metals.

(3) In using **nitroglycerine explosives** of all kinds—

(a) Don't store detonators with explosives. Detonators should be kept by themselves.

(b) Don't open packages of explosives in a storehouse.

(c) Don't open packages of explosives with a nail puller, pick, or chisel. Cartridges should be opened with a hardwood wedge and mallet, outside of the magazine and at a distance from it.

(d) Don't store explosives in a hot or damp place. All explosives spoil quickly if so stored.

(e) Don't store explosives containing nitroglycerin so that the cartridges stand on end. The nitroglycerin is more likely to leak from the cartridges when they stand on end than it is when they lie on their sides.

(f) Don't use explosives that are frozen or partly frozen. The charge may not explode completely, and serious accidents may result. If the explosion is not complete, the full strength of the charge is not exerted, and larger quantities of harmful gases are given off.

(g) Don't thaw frozen explosives before an open fire, nor in a stove, nor over a lamp, nor near a boiler, nor near steam pipes, nor by placing cartridges in hot water. Use a commercial or improvised thawer.

(h) Don't put hot water or steam pipes in a magazine for thawing purposes. Where large quantities of explosives are used, a special thaw house should be built, large enough to hold the quantity of explosives needed for a day's work.

(i) Don't carry detonators and explosives in the same package. Detonators are extremely sensitive to heat, friction, or blows of any kind.

(j) Don't handle detonators or explosives near an open flame.

(k) Don't expose detonators or explosives to direct sunlight for any length of time. Such exposure may increase the danger in their use.

(l) Don't open a package of explosives until ready to use the explosive; then use it promptly.

(m) Don't handle explosives carelessly. They are all sensitive to blows, friction, and fire.

(n) Don't crimp a detonator (blasting cap) around a fuse with the teeth. Use a cap crimper, which is supplied for this purpose.

(o) Don't economize by using a short length of fuse. Such practice is liable to result in a shot going off too soon.

(p) Don't return to a charge for at least one-half hour after a misfire. Hangfires and misfires are likely to happen.

(q) Don't attempt to draw nor to dig out the charge in case of a misfire.

(4) Gunpowder and smokeless powder must be protected from fire and moisture.

(5) Guncotton must be kept moist. It is very insensitive and requires a primer of dry guncotton. Dry guncotton deteriorates in the Tropics.

210. **Destruction of explosives.**—Such operations must be carried out under the direct charge of an experienced officer.

[illegible] picric acid can be destroyed by burning or detonating in [illegible]es. To burn, use inflammable material piled around the [illegible]nd ignite at a distance with a fuse or miner's squib. [illegible]*an also be* destroyed by burning. The dynamite, after removing wrapper, is burned in a similar manner to that just described. Detonation may occur, and the dynamite should be burned in small masses. All persons must be kept away from it when burning.

Gunpowder is destroyed by submerging in water. If no body of water is at hand it may be burned in small masses.

Smokeless powder is destroyed by burning in numerous small charges. Each charge of powder is ignited with a time fuse.

217. **Detonation.**—The detonation of an explosive is almost always affected by the detonation of a more sensitive explosive, of which a small quantity is placed in juxtaposition with the first and fired by mechanical shock, fuses, or electrical devices. Ordinary percussion cap composition contains a mixture of mercury fulminate, potassium chlorate, and antimony sulphide, to which powdered glass may be added in order to obtain increased sensitiveness. The caps for detonators are of pure copper, cylindrical in shape, closed at one end, and charged with an intimate mixture of 85 per cent mercury fulminate and 15 per cent potassium chlorate. Detonators are made in 10 sizes, numbered consecutively, and contain, respectively, 0.3, 0.4, 0.54, 0.65, 0.8, 1.0, 1.5, 2.0, 2.5, or 3 grams of the detonating mixture.

218. While the detonation of triton can often be secured with other caps, particularly if a boosting charge of powdered triton is used, the tetryl cap is necessary in order to **insure detonation.** This cap is furnished in two types, the **tetryl electric cap** and the **tetryl blasting cap.** The substance "tetryl" is the detonating agent in each type. The word tetryl is an abbreviation of the unwieldy name of a **complex** hydrocarbon. The tetryl in each type is detonated by a small charge of mercury fulminate The fulminate is detonated as in ordinary blasting or electric caps, i. e., by heat or shock.

219. **Precautions in detonation.**—Caps must be handled with extreme care. They can be detonated either by shock or heat. They must be packed and handled so as to avoid shock. The insulation used to close the mouth of the electric cap must not be injured. Caps must be kept dry. Avoid bringing the cap into contact with the explosive until the last practicable moment before use. Caps must not be pinched when crimping over the fuse. Crimp as near the open end of the cap as is practicable. Crimp caps before inserting in explosive. Caps must not be stored with explosives.

220. **Fuse.**—For the ignition of the detonator or, in the case of blasting explosives of the black powder class for the direct ignition of the charge, a fuse of one sort or another is used (figs. 179 to 182). In either case the shot firer is not exposed to the effects of the explosion.

Time fuse is furnished with a nominal rate of burning of 3 feet per one and one-half minutes. The rate of burning of each shipment of fuse is to be determined by test. Fuse is ignited by a match or fuse lighter. In igniting fuses with a match, the head of the match only gives a high enough temperature to ignite the fuse without fail.

Instantaneous fuse burns at a rate of 120 feet per second. This fuse is recognizable by the **red braid** used in its manufacture. The personnel executing demolitions must never confuse instantaneous fuse with the time fuse.

When it is necessary to splice different pieces of fuse of either kind, the ends to be joined should be cut obliquely. Care must be taken that the powder at the end of the cut does not fall out. The cut ends are placed carefully in juxtaposition, and before closing a few grains of powder should be dropped in and compressed between them. The splice is completed by wrapping with rubber tape if available, otherwise with any material at hand which will keep the ends in contact in their proper position. It is obvious that this splice must be completely protected from strain.

When a line of fuse is to be branched into two the same principles are followed, the double splice being connected and the same precautions taken in making up.

221. **Electrical detonation** is generally more reliable and convenient than detonation with fuses. The electrical current may be taken from any available source of electrical power. The blasting machine furnished will surely detonate 12 tetryl caps in series. The **Standard blasting machine** (fig. 183) generates 2.5 amperes at 45 volts with ordinarily vigorous use. The lead wires from the cap are carefully joined to the lead wire from the blasting machine. Small charges fired electrically are to be connected in **series,** large charges may be arranged either in series or parallel. Circuits arranged for electrical detonation should be always left open until just before detonation. Closed circuits are likely to cause detonation by induced currents from near-by electrical conductors or even from lightning. The electrical relation of the circuit for large charges must often be carefully computed. The tetryl blasting cap with 12-foot lead wires has a resistance of 1.5 ohms and requires a current of 0.4 of an ampere for detonation.

222. **Detonating cord** as issued is a lead tube 6 mm. in diameter, filled with pulverized triton. This cord is used both as a detonating agent for triton and as a means of securing instantaneous detonation of a number of charges. The cord itself must be detonated by a tetryl cap. The triton blocks are strung on the cord, after drilling the cap hole entirely through the triton block with the **cord drill.** Triton blocks can be strung like beads on the detonating cord and used as necklaces to cut posts, etc. Either the electric or the blasting cap may be used to detonate this cord. After the cord is detonated the wave of detonation passes along it practically instantaneously. All triton blocks through which the detonating cord is passed are detonated by it. The connecting up of systems of charges by detonating cord is done by slit connections as shown in figure 180. The cord is cut for this purpose with either a knife or the **cord slitter** (fig. 184). The passage of the detonating wave must occur from a main to a slit and wrapped branch. Wrapping a main about a branch would merely cut a section from the branch and **not** detonate it. Figures 185 to 186a show both the correct and the incorrect method of connecting up a system of charges with cord.

223. **Induced detonation** is of value in arranging simultaneous detonation. This is done by placing a blasting cap in a block of triton and detonating this by means of the mechanical shock in air from a charge detonated nearby. Air will carry over detonation in this manner to varying distances depending on the amount of explosive in the initial charge. To obtain successful **induced detonation** the charge detonated sympathetically must contain a firmly seated open cap whose mouth points directly toward the initial charge and must have no objects intervening. The distance to which induced detonation is practicable is:

Initial charge.	Distance.
	Inches.
1 block triton	24
2 blocks triton	36
4 blocks triton	48
[illegible] triton	60
[illegible] triton	72
[illegible] triton	96

[illegible] *must* be observed when igniting the fuse of the initial charge [illegible] *ber of charges* to be detonated by induced detonation. The

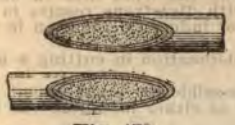


Fig. 179

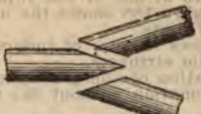


Fig. 180

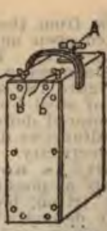


Fig. 183

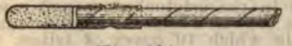


Fig. 181

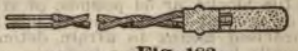


Fig. 182

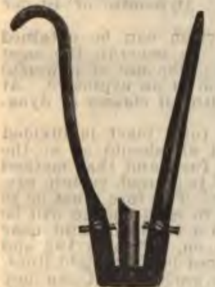
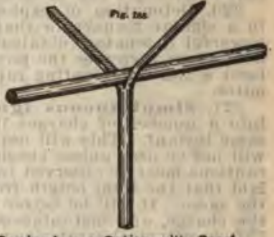
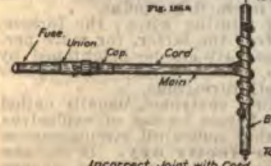


Fig. 184



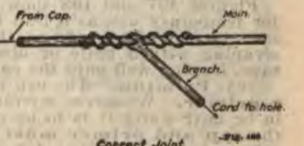
Beginning. a Splice with Cord.

Fig. 185



Incorrect Joint with Cord.

Fig. 186a



Correct Joint.

Fig. 186

flame from the match might be carried by the wind into an unprotected open mouth of one of the caps with disastrous results to the firing party. Figure 188 shows the use of induced detonation in cutting a number of posts.

Figure 189 shows the use of induced detonation in cutting a number of steel I-beam stringers.

Induced detonation of charges makes possible the arrangement of a simultaneous detonation without the use of either instantaneous fuse or electricity.

224. **As noted hereafter,** charges must be arranged as compactly as possible to attain the full effect of the explosion. Nevertheless, triton, both copperplated and noncopperplated, can be successfully detonated even when packed in the original unopened wooden containers and placed beside a box of triton that is then detonated. Figure 190 shows an actual test in which 19 boxes of triton, each containing 108 blocks, or 54 pounds, of triton, were detonated by the detonation of one box detonated with one tetryl cap.

225. Improvised means to attain detonation of certain explosives can occasionally be used. For instance, one of the most useful expedients is shown in figure 191. Here a service cartridge with the bullet extracted is used. The cap end of the shell is seated deeply in the dynamite. The powder taken from the shell is formed in a train as shown. Ignition of the train of powder with a match leads to the detonation of the shell cap and dynamite. Dynamite of 40 per cent or stronger can be detonated in this way.

226. Detonation of explosives other than triton can be obtained in a similar manner to that given for triton. In general, the most powerful detonators obtainable should be used. The use of powerful detonators increases the power of the detonation of an explosive. At least a No. 6 detonating cap should be used with all classes of dynamites.

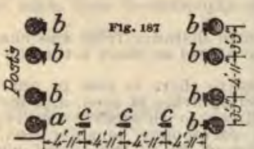
227. **Simultaneous ignitions.**—When a total blast is divided into a number of charges it is important that all should go at the same instant. This will not be easy with time fuse, and that method will not be used unless absolutely necessary. If it is used, certain precautions must be observed to avoid total failure. The fuse must be so laid that the total length from the firing point to each charge will be the same. It will be better to use time fuse to a common point near the charge, and instantaneous fuse from there on. Figures 192 and 193 show typical arrangements. The fuse need not be in straight lines, but must be laid out so that sparks from the burning end can not reach any part in front of it. Though not absolutely necessary with instantaneous fuse, it is well worth while to make different lines as nearly equal in length as possible.

In simultaneous ignitions by electricity the fuses are connected in **series;** that is to say, they are all placed in the same circuit, figure 194. A lead from the firing apparatus is connected to one wire of a fuse on one flank. The other wire of this fuse is connected to a wire of the next fuse, and so on, until the last fuse is reached, the second wire of which is connected back by a lead to the firing point.

Figures 197 and 198 show methods of jointing wires; the former, for temporary use, as a lead to a fuse wire; the latter, for more permanent use. The ends of the wires must always be brightened by scraping with a knife or otherwise. To insulate, wrap with rubber tape, lapping well onto the covering in both directions.

228. **Priming.**—The cap is inserted in a cartridge, usually called **a primer.** Whenever reference is made herein to use of explosives in or near water it is to be understood that under all circumstances he **cap and primer must be kept perfectly dry.** If but one mer is used, it should be placed near the center of the charge n the size and shape of the charge permit it to go in that posi- If the cartridges are placed in a drill hole, as in rock blasting ome demolitions, the primer is put in last with the cap end The cap may be inserted as shown in figures 195, 196, and

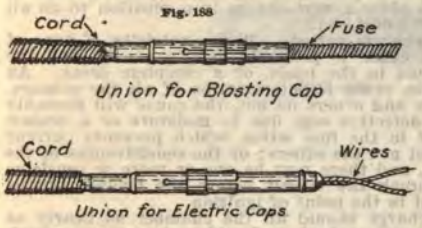
Fig. 187



a Initial detonation.
b Sympathetic with open detonators.
c Charges with open detonators for carrying over detonation.

Demolition of Round Timber Posts by Induced Detonation.

Fig. 188



Union for Blasting Cap

Union for Electric Caps

Use of Cord with Caps.

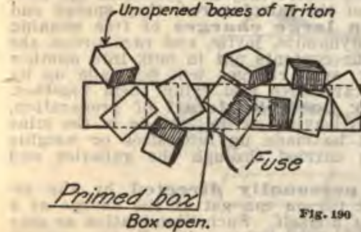


Fig. 190

Detonation of 20 Boxes of Triton.

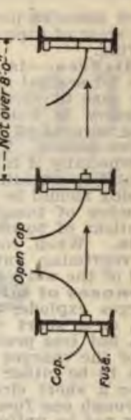
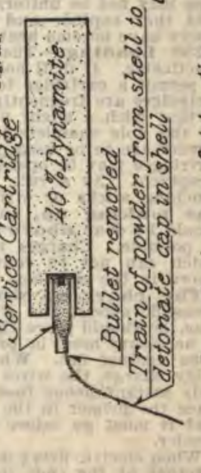


Fig. 189

Demolition of I Beam Stringers by Induced Detonation.

Fig. 191.



Improvised means of detonation.

199. Figure 195 applies to caps fired by **train fuse** and **no other method** may be used with such caps. **The projection** of about one-eighth to one-fourth inch of the cap case above the surface of the powder is **to prevent** the latter from **taking fire** from the sparks of the fuse and burning partially before the fuse goes, which, should it occur, will reduce the force of the explosion or may cause complete failure.

Primers must be prepared at a safe distance from the charge and from the store of caps and should be placed as short a time as possible before firing.

229. **Misfires.**—In case of a misfire there is risk in approaching the holes for several minutes, if electric firing is used, and for several hours in case of firing by fuse. Rules to this effect are laid down where safety to human life is a paramount consideration. They should be recognized in military operations to the extent which circumstances permit. There is also danger in attempting to reprime a charge, especially if tamping must be removed. The danger is reduced by care and by avoiding hard-metal tools and appliances; if possible, the tamping should be removed with wooden tools. In any case, leave a few inches of tamping above the charge undisturbed, then place several sticks of powder and a primer on top of the first charge and fire again. When conditions permit, it is better practice not to attempt repriming, but to place a new charge in a position to do all or a part of the work of the first charge.

The causes of misfires are various. With electricity, if none of the charges explode, the cause is probably due to overloading the machine, or a short circuit in the leads, or a complete break. An effectual, but less probable, cause is deterioration of all the primers. If part of the charges fire and others do not, the cause will probably be found to be either a defective cap, due to moisture or a broken bridge, or a short circuit in the fuse wires, which prevents current going through one fuse but not the others; or the sensitiveness of the caps may not be uniform, and there may be one or more so sensitive that they explode and break the circuit before the bridges of the others have become heated to the point of ignition.

230. **Loading.**—The charge should fill the chamber as nearly as practicable. If drill holes are used, they should be just large enough to permit a cartridge to slip down without jamming. In quarrying, cartridges are frequently slit open before they are placed in the hole, so that with a slight pressure of the tamping rod, they spread and fill the hole completely. **When large charges** of free running powder are to be used, such as dynamite, jovite, and rack-a-rock, the cartridges may be opened and the contents put in bulk into another receptacle. As a rule, however, such charges will be made up by bunching sticks or strings of cartridges and tying them together. **The making up,** and **every possible detail** of preparation, should be done **above ground,** leaving as little to do in the mine as possible. Charges must not be made up into sizes or weights which can not be conveniently carried through the galleries and placed in the chamber.

The charging should be **personally directed** by the responsible officer, and if but one person can get at the charge at a time, he should place the powder himself. Such illumination as may be necessary must be provided by closed lights, with effective precautions against fire. When the primer is placed in the middle of a bulky charge, the wires or fuse must be led out through the powder. Only instantaneous fuse can be so used. If time fuse must be used, place the primer in the middle of one side of the charge so arranged t it must go before any sparks from the fuse can set fire to the der.

hen electric firing is used, the wires of each fuse should be twisted ber at the ends to prevent the possibility of a chance current through the fuse and for identification for connecting to each and to the leads. Care must be taken that at no stage of the

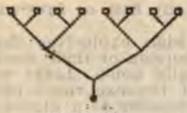


Fig. 192

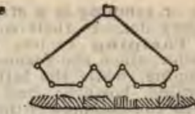


Fig. 193

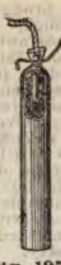


Fig. 195

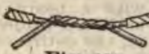


Fig. 197

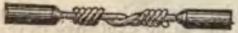


Fig. 198

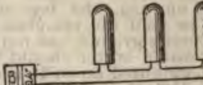


Fig. 194

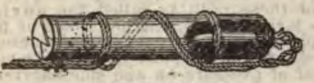


Fig. 196

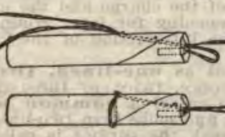


Fig. 199

loading or tamping is a strain brought on any fuse or fuse wires, or any injury done to their coverings.

231. **Tamping** is less important for high explosives than for gunpowder, since the former do a fair proportion of their work without tamping, while the latter does practically none. Light tamping is desirable, however, and may consist of the excavated earth replaced in the communication next to the chamber to a distance of 6 to 10 feet. The use of high explosives facilitates tamping, because so many charges can be placed in drill holes, which are easily tamped.

For drill holes in rock which will hold it, water is the best possible tamping, otherwise sand or stone dust may be used. If the hole points upward, the top should be covered with a board or thick brush to stop the tamping, which is blown out like a projectile. If neighboring ground can not be cleared for firing, the entire surface of the probable crater should be masked by brush or timbers piled upon it and weighted down if necessary.

232. **Effects of explosion.**—It may be assumed as sufficiently exact for present purposes that charges of the same explosive develop total energies directly proportional to their weights. This energy is exerted in all directions in compression of the surrounding medium. The distance at which this disturbance remains sufficient to destroy galleries is called the **radius of rupture,** R. R. The surface joining the ends of these radii is called the **surface of rupture.**

If the charge is large enough, further relief of pressure is afforded by the bodily displacement of a part of the surrounding medium on the side which presents the shortest distance from the charge to the surface. The relief of pressure on one side shortens all radii of rupture which have a component in that direction, but does not appreciably affect those which have no such component. Hence, when material is displaced the surface of rupture is ellipsoidal; when no material is displaced it is spherical. Figure 201 illustrates in a very general way the supposed relations of craters and radii of rupture. It is not based on exact data.

The space left by this bodily displacement of material is called a **crater.** The determination of the crater which a particular charge in a particular place will produce, or of what charge must be put in that place to produce the given crater, or where a given charge must be placed to produce a desired crater, are problems constantly arising in military mining.

Figure 200 shows a cross section of a typical crater in earth. The position of the charge is indicated: *AB* is the surface of the ground; *CD* is the **line of least resistance,** commonly designated L. L. R. or, in formulas, *l; DE* is the **crater radius,** and *CE* the **radius of explosion.** All the elements of the crater are reckoned with respect to the position of the charge and the opening of the original ground surface. This opening for level ground is circular in form and is approximately the intersection of the spheroid of rupture by the ground surface.

Craters are designated as **one-lined, two-lined,** etc., according as the diameter is once, twice, or three times the L. L. R. A two-lined crater is also called a **common mine;** less than two-lined, **undercharged;** and more than two-lined, **overcharged.** A mine which does not break the surface is called a **camouflet.**

When a crater is formed the part of the total work of the charge represented in crater effects is assumed to be proportional to the volume of earth actually moved. As a part is thrown vertically upward and falls back loosely into place (fig. 200), the hole actually left does not represent the earth moved. The total volume moved is assumed, from many experiments, to be represented by the frustum of a cone, shown in section in figure 200, having the crater opening its larger base, a circle of the diameter L. L. R. for its smaller and L. L. R. for its height. For each cubic yard of volume of a frustum a certain weight of explosive is allowed, and it is that the corresponding weight of charge is ascertained. **The weight** is the quantity of powder required to **throw out 1**

cubic yard. It has been experimentally determined for gunpowder and is deduced for other explosives from their corresponding intensities.

The crater volume, or volume of the conical frustum (fig. 200), may, for any given ratio of height and crater radius, be expressed by the cube of the height, L. L. R., multiplied by a numerical constant, and hence the weight of explosive required to produce a crater of corresponding proportions may also be expressed by t^3 multiplied by a constant. The constant varies with the character of the material, as well as with the proportions of crater.

233. Table II gives constants for various classes of materials and for craters from 1 to 6 lines, the former practically a camouflet and the latter the largest that can be depended upon for results. The table also gives constants from which the R. R. may be determined.

TABLE II.—**CONSTANTS** FOR DETERMINING **CHARGES** AND **RADIUS OF RUPTURE** OF MINES.

Kind of material.	Camouflet, 1-line.	Undercharged, 1½-line.	Common, 2-line.	Overcharged.				Remarks.
				3-line.	4-line.	5-line.	6-line.	
Light earth	0.005	0.012	0.027	0.081	0.185	0.351	0.594	These numbers to be multiplied by l^3 for charges of 50 per cent dynamite in pounds.
Common earth	.006	.015	.033	.094	.229	.433	.733	
Hard sand	.007	.019	.042	.126	.288	.546	.924	
Hardpan	.008	.023	.050	.150	.343	.650	1.100	
Ordinary brick masonry.	.010	.026	.057	.161	.391	.741	1.254	
Medium rock or good *new* brickwork.	.013	.034	.075	.225	.514	.975	1.650	
Best *old* brickwork	.014	.038	.083	.250	.569	1.079	1.826	
Rad. rupture Hor.	1.0	1.4	1.7	2.5	3.4	4.0	5.0	These numbers to be multiplied by l for radius in feet.
Rad. rupture Vert.	1.0	1.0	1.1	1.2	1.7	2.0	2.5	

For gun cotton or 75 per cent dynamite, reduce charges found from above table 40 per cent; for ammonal, reduce 50 per cent.

Strength of triton.—If triton is taken as being 7/5 as efficient as 50 per cent dynamite and the constants given in the formulæ and tables for 50 per cent dynamite be therefore multiplied by 7/7, successful results may be obtained.

The weight of charge may be determined from Table II. It is to be noted that the user of this table must exercise his judgment in classing the soil under the headings given, so that it can not be said that the table gives charges absolutely. If the mine is important, powder not scarce, and no information has been obtained from actual firings in the soil, the tabular charges should be increased 10 per cent for large quantities and 50 per cent for small ones. It is to be remembered that while if more powder than necessary is used the excess may be said to be wasted, if less than the proper amount is used, not only is the total quantity used wasted, but the time and labor spent in getting it into place are also wasted, and the opportunity to gain advantage by successful firing is lost. In all uses of explosives in mining the maxim for the first charge should be, **do not spare the powder.** On the other hand, every charge fired should be carefully observed, and whenever it is vious that more powder than necessary has been used advantage should be taken of the experience gained to economize powder in future firings. **The worst mistake** that can be made is having **the first charge too small.**

234. **Land mines.**—This term is applied to mines or groups of mines usually formed by excavation from the surface and designed to be exploded at the moment the enemy is over them. Such mines are usually employed in front of defensive positions and in connection with visible obstacles. It is **not permissible** to plant such mines in any ground which is **not obviously** prepared for defense. Any person who ventures on space so prepared does so at his peril, but if there is a road or path open to passage through such ground mines must not be placed therein, or in a place where the explosion would injure persons occupying the road. If any defensive works or recognized obstacles are thrown across the road, indicating that it is closed to traffic, the road may be mined to a reasonable distance in front of them.

The charges are placed deep enough only to avoid artillery projectiles. If no artillery fire is to be expected they may be placed just under the surface. If a bore hole is sufficient the charge is placed at the bottom and the hole well tamped. If an open pit is dug the mine chamber should be in firm ground at one side and the hole back filled and well rammed.

The depth fixed, the charge may be adjusted to give a 2 or 3 line crater. The mines may be in one or more rows. Two rows, 30 to 40 yards apart, are a good arrangement. The intervals between mines in a row should be such that the craters will nearly but not quite join. The positions of the mines should be concealed as completely as possible and further sophisticated by disturbing the ground slightly at points where there are no mines and so situated as to suggest a systematic arrangement.

A fougasse is a land mine in which the volume of the crater is artificially prepared to increase its range and effect. Figure 202 shows the form which has been most used. The earth excavated must be piled around the pit, as shown, and well tamped to prevent the charge blowing out behind the stones. It is not necessary to undercut the bank as shown in the section. If the soil will not stand it may be thrown out to its natural angle and back filled and tamped against the stones. A charge of 25 pounds should scatter a cubic yard of stones over an area 200 by 100 yards.

This form is difficult to conceal and very easily destroyed by the enemy's fire. Another form, with the axis vertical, is shown in figure 203. It is possible to conceal it by sprinkling earth over it, and an automatic firing device may be used with it, which is not practicable with the inclined form.

235. **The igniting means** may be instantaneous fuse or electricity. Fuses or wires should be laid in trenches 1 to 3 feet deep. Mines are classed with respect to the method of firing as **judgment** and **automatic. Judgment** mines are controlled from a firing point and can be fired only at the will of the operator. **Automatic** mines are arranged to be fired by the disturbance of some apparatus in or near them. Automatic and judgment firing are often combined for the same mines. **If firing by cap,** the automatic firing device takes the form of a **mechanical trigger,** which may be operated by the pressure of feet on the ground over it, or by the pulling of a wire stretched along the line at such height as to be tripped by
With electric firing this device is called a **circuit closer,**
ctuating force operates to close a contact which completes
circuit from the battery to the fuse.

and operation of land mines will ordinarily be the work
troops supplied with approved apparatus.

actics.—In siege operations mining is done at close
is, or should be, opposed by countermining by the
then a double purpose in view—to reach the orig-
placing the charge where intended and firing it,

and while so doing to detect and circumvent any attempt of the enemy to interfere or to prosecute any enterprise of his own.

The only information of neighboring operations which is obtainable results from the **sound of working** carried through the earth. In compact soil an ordinary blow of a pick can be heard at a distance of 40 feet, and the most careful working is audible to a distance of 20 feet. Other sounds, such as rumbling of trucks, and especially tamping, can be heard farther. These distances vary with the character of the soil and the skill of the listener. When more than one gallery is driven they should be parallel and not farther apart than twice the range of hearing, so that an enemy's gallery penetrating between them will be heard from one or both. Returns may be run out from the extreme galleries to detect the sound of working on the flanks. Such galleries are called **listeners.** They should not be large.

Efforts must be made to detect the enemy's working and to avoid, so far as possible, giving him like information. At occasional and irregular intervals all work should cease, all extraneous sounds be cut off, and men with quick and trained hearing should listen for sounds of working and estimate the distance and direction. A map of the galleries should be kept, and whenever two headings are approaching, listening should be done in them and the estimates made by the men compared with the measurements on the map as a check on the range of hearing. Accuracy of perception of the sounds may be tested by tapping messages across.

When hostile parties have approached within destructive range of each other the one who fires first is the winner, but the nearer he is or the longer he holds his fire, the more complete the victory. Each party will be on the alert to discover when the other party is getting ready to fire, and hence the greatest care must be taken to sophisticate the sounds connected with loading. Digging should continue at some point near the end, and all movements of trucks or other operations which make a noise should be continued not less frequently, and certainly not more frequently, than during the digging. Especially should tamping be cautiously done. **The most probable mistake is premature firing,** and it should be impressed upon all concerned that it is **better to come into actual collision** with the enemy's miners than to fire prematurely.

Galleries are much more vulnerable to a side than an end attack. If the enemy's heading can be located, an attempt should be made to get a position on one side of his gallery. The best position is nearly abreast of the end, a little in rear, so that if he is still digging a considerable length of his gallery will be destroyed, or if he is loading or loaded his mine will be exploded.

For long galleries the difficulties of ventilation and earth disposal may make it advisable to take a new departure. The heads of galleries are brought on a line, or nearly so, branches run forward from each so as to end at intervals of one and one-half times the depth below the surface, charged for common mines and fired simultaneously. An elongated crater is produced, which becomes a lodgment for new galleries as well as an advanced parallel in any system of surface approaches. The old galleries are reopened to form rear communications. It has frequently happened that entire underground operations have been directed to the single purpose of forming such an advanced trench in a position which could not be reached on the surface.

It will rarely be possible to get close enough to do serious damage with a camouflet, though in some cases it might be advantageous to avoid breaking ground at the surface. The maximum camouflet charge—one-sixth to one-eighth of common mines—gives an H. R. R. somewhat less than the L. R. R., which will usually be not more than 15 feet, while a 6-line crater has an H. R. R. of 5 times L. R. R. As countermining will usually result in a crater, considera must be given to its situation with respect to the surface work so it will be an advantage if possible and certainly not a detrimen

DEMOLITIONS.

237. **Military demolitions** have for their purpose to destroy or make unserviceable any object in the theater of war the preservation of which would be unfavorable to the army or favorable to the enemy, excepting always objects neutralized by international convention or the laws of war.

The principal objects of demolition may be divided into **two general classes,** viz:

Natural or **artificial objects** having **no intrinsic** or **permanent value,** such as accidents of ground and structures of purely military character; and

Natural or **artificial objects** having intrinsic or permanent value, or **adapted to useful purposes** in time of peace, such as buildings and communications.

Demolition is permissible only under a **military necessity.** For the first class of objects above the military necessity is obvious, since the destruction is aimed directly and exclusively at the enemy's fighting efficiency.

For the second class, the destruction affects others besides the armed enemy, and for this class the existence of a military necessity justifying demolition can not be presumed but must be determined at the moment, and the amount and character of destruction or disablement explicitly ordered by competent authority.

Demolitions of a local character, which have no effect elsewhere, may be made on the order of the immediate commander, as may also demolitions of a more serious character, but which are necessary to the safety of a local force. For example, a small force in retreat may interrupt a bridge to avoid capture, but the destruction should go no farther than is necessary to produce the result immediately desired by detaining the pursuers long enough to enable the pursued to make their escape. Demolitions which are intended to, or in their ultimate consequences may affect a larger force or a greater territory, must be ordered by the commanding general of an army or other force operating independently. In case of doubt, orders should be sought from the highest accessible commander. An officer upon whom work of demolition is devolved should, if not provided with proper orders, ask for them.

238. **Methods employed.**—Demolitions may be made by **fire,** by **mechanical means,** or by **explosives.** Fire is the *only* recourse when absolute destruction is necessary, as in case of food supplies, munitions of war, structural materials, etc. Soluble matter, as gunpowder, sugar, salt, etc., might be destroyed in water, but this method is laborious. Burning is equally effective and much easier. For quick results with slow-burning materials a quantity of highly combustible stuff must be collected. A small fire gains headway very slowly and much time is lost. Care must be taken that the fire does not spread to objects not intended to be destroyed.

239. Demolition by mechanical means is too simple to require, and too varied to permit, detailed description. Reference is made to a few cases in which the best method may not be obvious.

Abatis is difficult to destroy. If the trees are dry, time suffices, and concealment is not essential, fire is best; otherwise, if working from the front, cut up and carry away enough trees to make a passage through. If working from the rear, loosen the fastenings of the butts and haul away bodily with ropes.

Wire entanglements must be cut with nippers, the more and shorter the pieces the better. Wire may be cut with an ax or machete if a block of wood is held behind it as an anvil. **Trous de loup** are leveled by shoveling the walls into the pits, or bridged with planks, fascines, or other materials.

sades and **stockades** may be cut down with axes or saws, or th may be dug away from one side and the logs pulled over.

Railroads.—Operations may be directed against rolling stock, bridges, culverts, tunnels, or track, or accessories, such as water stations, telegraphs.

Locomotives are temporarily disabled by removing valves or other small vital parts; permanently by building a fire in a dry boiler or by detonating a charge of explosive in the boiler. In haste, piston or connecting rods, links, etc., may be destroyed by explosives, or a hole may be blown in the bottom of the tender tank. Cars may be burned or wrecked by collisions or derailment. The best places are in deep cuts or tunnels. A head-on collision in a tunnel will put it out of use for some time.

Wooden bridges may be burned or small ones may be pried off their seats by levers or dragged off with tackle.

Track may be destroyed by taking it up, burning the ties, heating the rails on fires and twisting them with bars through the bolt holes, with a chain and lever, or a hook and lever (fig. 167a). Twisting is much better than bending, as twisted rails must be rerolled before they can be used. The rail should be hot for the greater part of its length, so as to take a long twist. **A quick track demolition** requiring considerable time to repair, but not injuring the track material, may be made by loosening the ties over a stretch of track, taking off the end fishplates, putting a line of men along one side, two men to each tie, and turning the track over bodily. This plan works best on a high embankment.

Telegraph lines are temporarily disabled by **breaks,** in which wires are cut, **grounds,** in which the wires are connected to the ground, and **crosses,** in which a metallic connection is made between the wires. **A ground** may be made by connecting a wire to the rail or to a bar or plate of metal in damp earth. Copper is best. A connection with water or gas pipe forms a ground. All faults should be carefully concealed from view, so as to prolong the time necessary to locate them. If a raid is made on a telegraph office, remove the instruments, bare and brighten the ends of all wires, and tie them together with a wrapping of brightened copper wire. Incoming and outgoing wires should be tied separately.

To destroy a telegraph line cut down and burn poles, cut and tangle wires, and break insulators.

240. **Demolition equipment of engineer troops.**

Company tool wagons.	On the 2 tool wagons of pioneer company.	On the 1 tool wagon of mounted company.
Augers, earth, handled	2	1
Augers, ship, ¼-inch, handled	2	1
Bars, pinch, large	2	1
Bars, wood, tamping	2	1
Boxes, cap	2	1
Boxes, match	2	1
Chisels, cold	2	1
Circuit detectors	2	1
Crimpers	2	1
Drills, single-bit, long	2	1
Drills, single-bit, short	2	1
Hammers, sledge, 8-pound	4	2
Magneto exploders	2	1
Pick mattocks, E. D. pattern, "intrenching," handled	4	2
Reels, wire, firing	2	1
Shovels, E. D. pattern, "intrenching"	8	4

Demolition equipment of engineer troops—Continued.

Company tool wagons.	On the 2 tool wagons of pioneer company.	On the 1 tool wagon of mounted company.
Spoons, miner's, long	2	1
Wire, firing, double lead, No. 14, feet	2,000	1,000
Cord, drill	2	1
SUPPLIES.		
Caps, tetryl, nonelectric	100	50
Caps, tetryl, electric	200	100
Explosive, pounds	200	100
Fuse, Bickford, feet	200	100
Fuse, instantaneous, feet	200	100
Matches, safety, boxes, dozen	1	½
Tape, insulating, rolls	2	1
Twine, hemp, 2-ounce balls	2	1

Pack train.	On the 4 mules of pioneer company pack train.	On the 8 mules of mounted company pack train.
Augers, ship, 1⅛-inch, handled	2	4
Bars, pinch, small	2	4
Boxes, cap	4	8
Boxes, match	4	8
Boxes, pack, Nos. 2 and 3	4	8
Buckets, canvas	2	4
Chisels, cold	2	4
Crimpers	4	8
Drills, single-bit, short	2	4
Hammers, sledge, 8-pound	2	4
Knives, clasp	4	8
Pick mattocks, E. D. pattern, "mining," handled	2	4
Pliers, side-cutting	4	8
Rolls, canvas, for tools	4	8
Shovels, E. D. pattern, "mining"	2	4
Spoons, miner's, short	2	4
Cord drill	4	8
Cord slitter	4	8
SUPPLIES.		
Caps, detonating	200	400
Cord, detonating, spools	8	16
Explosive, pounds	180	360
Fuse, Bickford, feet	400	800
Fuse lighters, Bickford	120	240
tches, safety, boxes, dozen	2	4
pe, manila, ½ inch diameter, 18 feet lashings	4	8
ine, hemp, 2-ounce balls	4	8
ons, detonating cord	48	96
, copper, No. 30, ¼-pound spools	4	8

241. In the **execution of a demolition with explosives** there must be considered:

1. **The object of the demolition.**
2. **The relation of the charges, their individual and joint effect, their location and accessibility, the nature of the tamping, and the distance of the personnel when detonation occurs.**
3. **The nature of the material to be blasted and the precautions required in placing the charges and protecting them from moisture.**
4. **Computation of the individual charges.**
5. **Method of detonation.**
6. **The requirements of time for executing the work, personnel, explosive, caps, fuses, etc., and building material.**
7. **A few instructions for the personnel which is to detonate the charge.**
8. **Final arrangements and precautions to be taken in cases of important demolitions. These should be prescribed by orders of the commanding officer.**

242. The **text of this manual** gives the data required for the proper consideration of nearly all of the above. Only general rules are laid down. The details for working out each particular demolition will vary greatly.

243. The **object** of the demolition can only be properly attained through accurate grasp of the tactical situation. It is unpardonable to completely wreck a line of communications which friendly troops may require in the near future. It is likewise unpardonable to fail to use every means to wreck a line of communications that is to pass immediately into hostile control for a long future period. **Demolitions of bridges or other important structures should not be executed except by authority of the commander in the area involved, or in extreme emergency.**

244. The two general **types of charges are: Concentrated charges** and **charges in a row. Concentrated charges** in which the explosive is bunched are the rule. One cap in one triton block will detonate completely all blocks placed closely around the primed block. For **maximum effect, the charge should approximate the cubical shape.**

245. **Charges in a row** or **small distributed charges** are the exception. Their adaptability is discussed hereafter. If the blocks are placed closely together, one block detonated will detonate the entire row. As a precaution, a string of blocks placed on detonating cord may be placed along the entire row.

If the charge is placed in small **drilled holes,** the triton stick is to be used. Otherwise the triton block is admirably adapted for bunching into masses of the most effective form.

In **priming** the charge, the cap is to be firmly seated in the cap hole, with the fuse (if used) securely crimped in the cap or the lead wires connected securely (if electrical detonation is used). It is notable that triton will usually detonate with a No. 6 commercial cap if a boosting charge of powdered triton is used. If detonating cord is used, the cord must be dry when passed through the triton block. Methods of priming dynamite with both blasting and electric caps are shown.

246. The problem of securing **simultaneous detonation** is one calling for much practice. The various methods of obtaining simultaneous detonation are, in order of excellence:

First. Electricity with detonating cord.
Second. Electricity.
Third. Time fuse with detonating cord.
Fourth. Time fuse with induced detonation.
Fifth. Time fuse with instantaneous fuse.
Sixth. Time fuse.

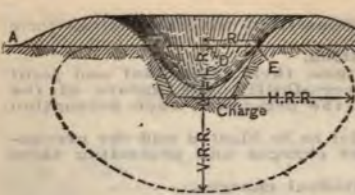


Fig. 200

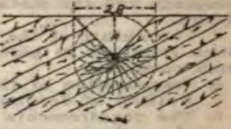


Fig. 204

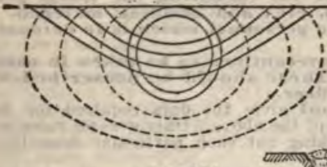


Fig. 201

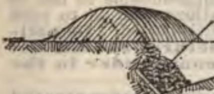


Fig. 202

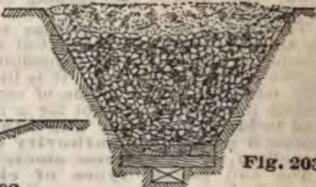


Fig. 203

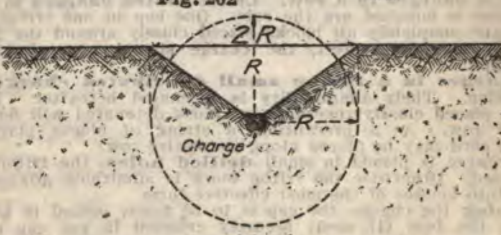
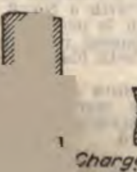


Fig. 205



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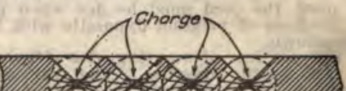


Fig. 206

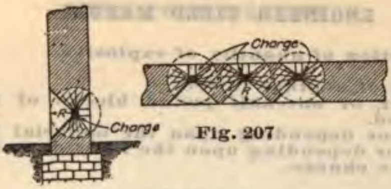


Fig. 207

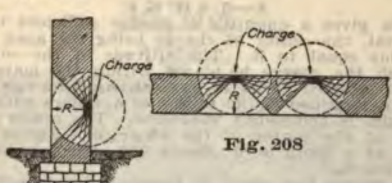


Fig. 208

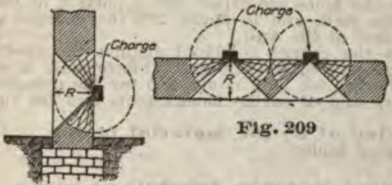


Fig. 209

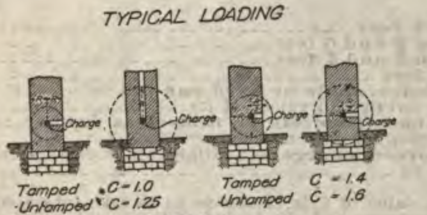


Fig. 210

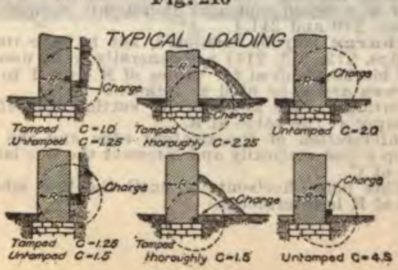


Fig. 211

247. **Calculation of quantity of explosive.**

Let **R=radius of rupture in feet.**
Let **N=number of one-half pound blocks of triton required.**
Let **K=a factor depending upon the material blasted.**
Let **C=a factor depending upon the location and tamping of the charge.**

Then $N=5/4\ R^3\ K\ C$

This formula gives a quantity of charge sufficient to blast out a cone of material, the center of charge being the apex and the base having a radius equal to R. The altitude of the cone equals the depth at which the charge is placed within the material. Such a charge will be referred to as **a breaching charge.** The radius of rupture so determined is the radius of a sphere within whose surface all material is completely shattered. The center of the sphere is, of course, at the center of the **charge.** Figure 204 shows a charge placed at a depth of R; figure 205 shows a charge placed at a depth less than R.

Figure 206 shows the effect of blasting a masonry wall with a series of charges inserted in holes driven to the center of the wall.

In figure 207 the holes are driven but a portion of the distance to the center of the wall, and in figure 208 the charges are placed in cavities in the face of the wall.

In figure 209 the charge is placed against the face of the wall. R is indicated on each of the figures. This formula is of general use in computing charges for land mines and for the demolition of structures of masonry and of earth embankments and for the blasting of rock.

248. **The value of K, the material factor,** is to be selected from the following table:

Good masonry, concrete or rock.

	Value of K.
R under 3 feet	**0.5**
R between 3 and 5 feet	**.4**
R between 5 and 7 feet	**.35**
R over 7 feet	**.30**
Poor masonry, shale or hard pan (all values of R)	**.30**
Ordinary earth (all values of R)	**.07**
For very **dense concrete or first-class** masonry multiply above factors for good masonry by	**1.3**
For **reinforced concrete** multiply above factors for good masonry by	**2.0**

249. The value of C is chosen so as to take into account the location of the charge and the extent of the tamping. C equals 1.0 for charges placed in a bored hole and thoroughly tamped as in a land [illegible] (See figs. 210 and 211.)

250. The charge may be computed, but to save time the charts (figs. 212, 213, 214) are generally to be used. These give [illegible] blocks required for values of R from 1 to 35 feet.

[illegible] are to be used as follows:

[illegible] ght edge horizontally cutting the left side of the [illegible] the value of R.

[illegible] on of the straight edge and the curve labeled [illegible] vertically and intersect the line labeled with the

[illegible] rizontally until the line labeled with the [illegible]

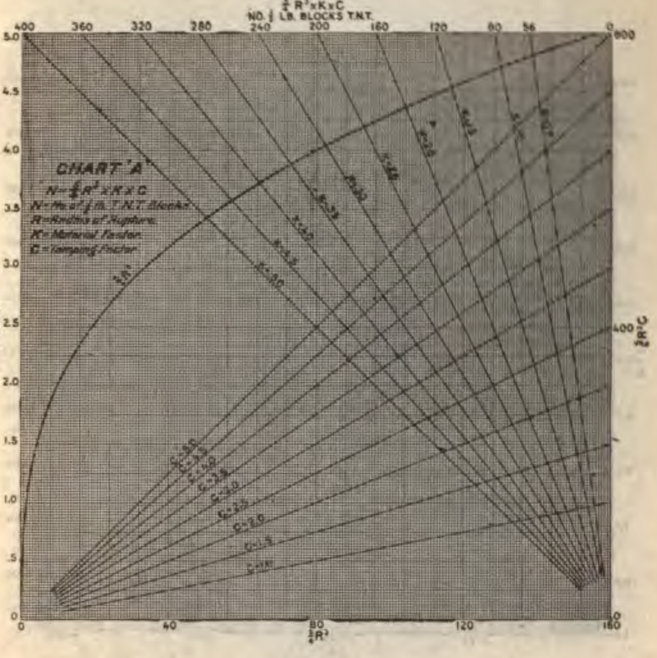
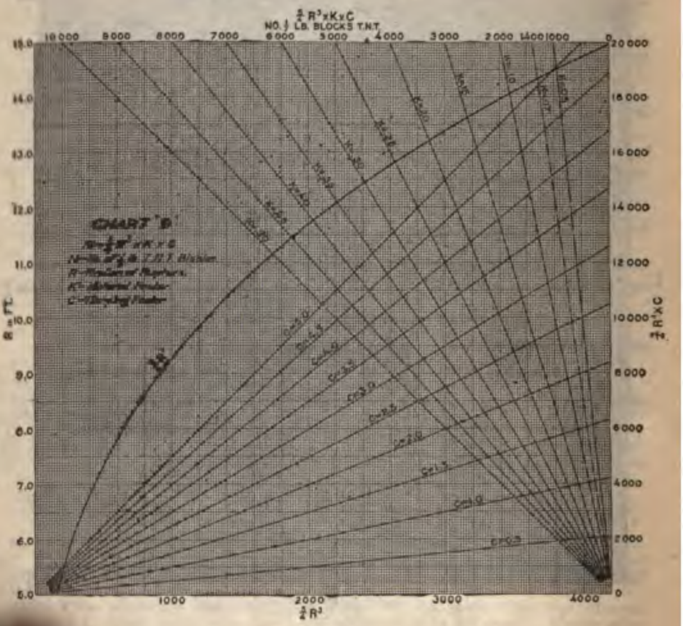

¾ R³xKxC
NO. ½ LB. BLOCKS T.N.T.
400
360
320
280
240
200
160
120
80
56
0
800
400
0
¾R³C
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
R in FT.
0
40
80
120
160
¾R³
CHART "A"
N = ¾R³ x K x C
N = No. of ½ lb. T.N.T. Blocks
R = Radius of Rupture
K = Material Factor
C = Tamping Factor
¾R³
K=5.0
K=4.5
K=4.0
K=3.5
K=3.0
K=2.5
K=2.0
K=1.5
K=1.0
C=5.0
C=4.5
C=4.0
C=3.5
C=3.0
C=2.5
C=2.0
C=1.5
C=1.0

Fig. 212

Fig. 213


¾ R³ x K x C
NO. ½ LB. BLOCKS T.N.T.
10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1400
1000
0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
R = FT.
20 000
18 000
16 000
14 000
12 000
10 000
8 000
6 000
4 000
2 000
0
¾ R³ x C
1000
2000
3000
4000
¾ R³
CHART "B"
K=60
K=55
K=50
K=45
K=40
K=35
K=30
K=25
K=20
K=15
K=10
K=7.5
K=5.0
15
C=5.0
C=4.5
C=4.0
C=3.5
C=3.0
C=2.5
C=2.0
C=1.5
C=1.0
C=0.5

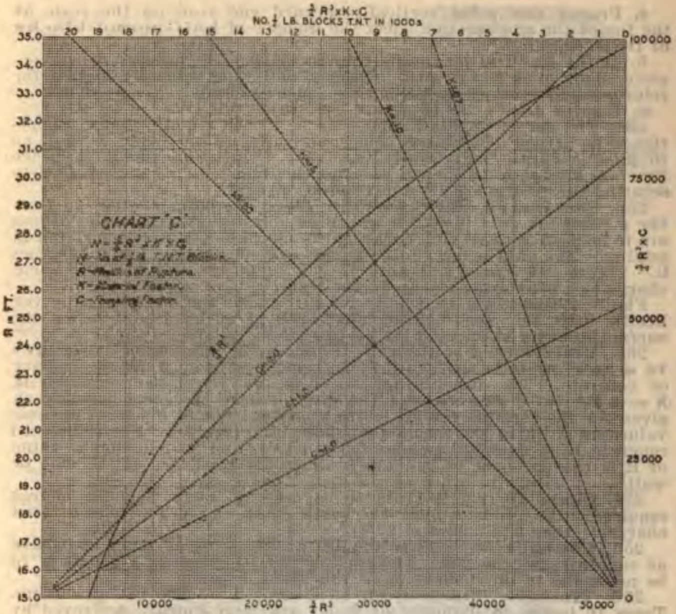
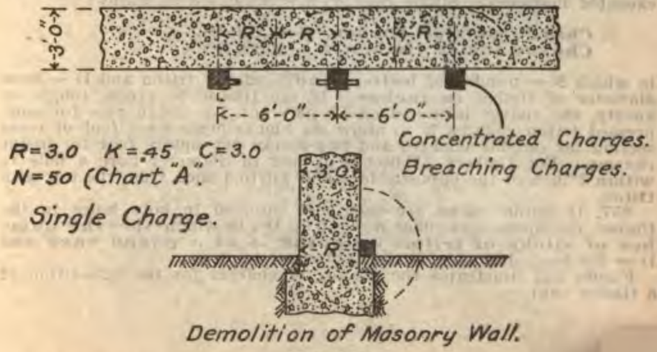


Fig. 214



Demolition of Masonry Wall.

Fig. 215

4. Project this point vertically upward and read on the scale at the top of the cross-section sheet the number of **half-pound blocks** of triton required.

5. If the material blasted is reinforced concrete or very dense concrete, determine N for good masonry and then multiply by 2.0 for reinforced concrete or by 1.3 if very dense concrete.

6. Figures 215 to 218 illustrate the use of this curve.

251. The curves enable K and C to be varied readily, and the experience in actual demolitions will readily determine valuable data as to more accurate values of K and C. Demolitions made in peace time are always to be viewed as experiments conducted with a view to securing information as to the value of K and C.

252. **Shattering charges** differ from breaching charges in that the material is only loosened and is not blasted away. Such charges are to be used in quarrying, as an aid to mechanical demolitions, and in mining. The shattering effect extends one and one-half to two times R. Figure 219 shows a breaching charge to the left and the same charge as a shattering charge to the right.

Figure 220 shows a charge placed in a counter mine to destroy the hostile drift M. This charge must be kept at least 2 R below the surface to avoid shattering the surface of the ground.

253. **Distributed charges, breaching charges—Charges in a row** are to be used to breach through slabs or walls of masonry or concrete. The formula for the computation of such charges is **$N = 4 R^2 \cdot K \cdot C$ per yard.** The symbols have the same meaning as given for the formula for breaching charges. K and C have the same values as given in the formula for breaching charges. For reinforced concrete K is doubled, as previously noted, and in addition a value of R is chosen equal to one-fourth times the thickness of the slab or wall.

254. **Chart D** (fig. 221) is to be used in computing the charge required. Its use is similar to charts A, B, and C for concentrated charges. (See figs. 222 and 223.)

255. **Charges in a row** require about twice as much explosive as concentrated charges. Their use is the exception and generally to be restricted to the demolition of thin slabs or walls.

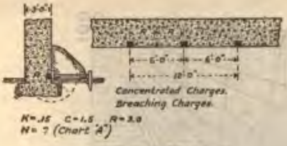
256. **Timber.—Timber** can be destroyed by fire or by cutting. Trees 16 inches in diameter or under are more quickly destroyed by cutting than by explosives. Explosives are used principally where the demolition has to be delayed until a given moment and then executed instantly. Single charges are computed as follows:

Charge outside timber, $N = .03\ D^2$,
Charge inside timber, $N = .008\ D^2$,

in which N = number of **half-pound** blocks of triton and D = least diameter of timber **in inches.** If the timber be green, tough, or knotty, the charge is increased 50 per cent. A rough rule for compressed triton charges is to allow six blocks per square foot of cross section for outside charges and two blocks per square foot for inside charges. For timbers 24 inches or less in diameter bore a hole to within 1 inch of the opposite face and fill to 1 inch from the top with triton.

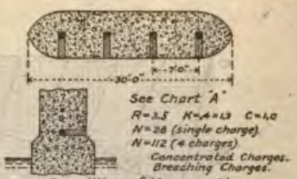
257. If triton sticks are used and inserted in bore holes in the timber, the formula becomes $N_1 = .01 \times D^2$, in which N_1 = **the number of sticks of triton weighing .4 of a pound each** and D = the least diameter of the timber **in inches.**

Figure 224 illustrates the placing of charges for the demolition of a timber bent.



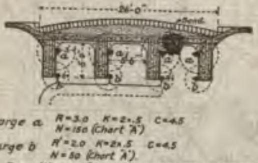
Demolition of Masonry Wall.

Fig. 216



Demolition of Masonry Pier.

Fig. 217



Demolition of Reinforced Concrete Viaduct.

Fig. 218

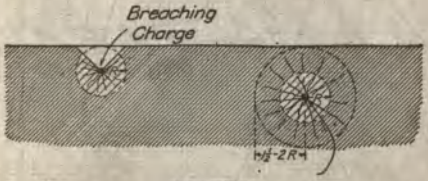
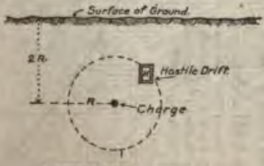


Fig. 219



Explosions in Counter Mines.

Fig. 220

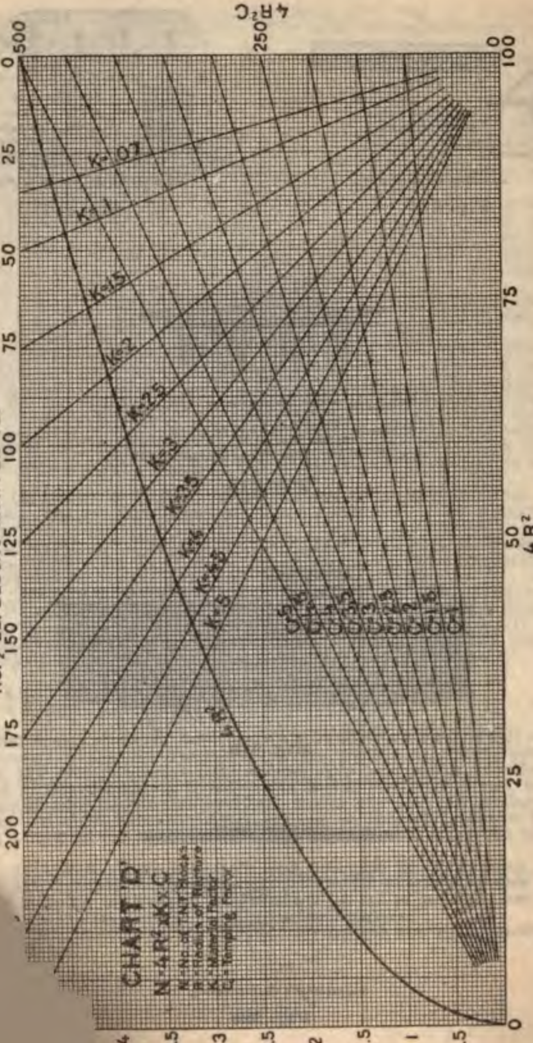

4 R² x K x C
NO. ½ LB. BLOCKS T.N.T. PER YD.
4 R²C
0
25
50
75
100
125
150
175
200
250
500
0
25
50
75
100
4 R²
R = FT.
0
.5
1
1.5
2
2.5
3
3.5
4
K=.07
K=.1
K=.15
K=.2
K=.25
K=.3
K=.35
K=.4
K=.45
K=.5
C=5
C=4.5
C=4
C=3.5
C=3
C=2.5
C=2
C=1.5
C=1
4 R²
CHART 'D'
N=4 R² x K x C
N=No. of T.N.T. Blocks
R=Radius of Rupture
K=Material Factor
C=Tamping Factor

Fig. 221

The following table gives the value of D^2 and is to be used in computing the charges required:

VALUE OF D^2.

D.	D^2.	D.	D^2.	D.	D^2.	D.	D^2.
6	36	14	196	22	484	30	900
7	49	15	226	23	529	31	961
8	64	16	256	24	576	32	1,024
9	81	17	289	25	625	33	1,089
10	100	18	324	26	676	34	1,156
11	121	19	361	27	729	35	1,225
12	144	20	400	28	784	36	1,296
13	169	21	441	29	841		

Figure 225 illustrates the placing of charges for the cutting of a number of timber stringers.

Figure 226 shows the charges placed for the destruction of round timbers by inserting the triton in bored holes.

258. **Steel.**—Bessemer steel crystallizes, breaks, and throws its fragments generally away from the explosive. Open-hearth steel tears and may throw fragments in any direction. These fragments are frequently large and projected with force enough to carry them from 400 to 1,000 yards or more. Extra precautions must be taken to shield the firing detachment. Tree trunks 12 inches or more in diameter make good field shelter.

For the purpose of computing the charges required to cut heavy steel I-beams and built-up steel girders and columns the following formula is to be used:

$N = A \times \frac{3}{4}$.
N=number of *one-half pound blocks* of triton required.
A=area in *square inches* of the cross section of the steel member to be cut.

A number of illustrative examples are attached, by means of which the use of the formula will be evident. It is to be noted that the charge must be placed against the steel member so that the greatest quantity of explosive will be near the heaviest part of the cross section.

To prevent an overestimate of what can be done with the quantity of triton carried, the study and use of the above formula are recommended.

A handy rule, applicable only to $1\frac{3}{4}$ by $1\frac{3}{4}$ by $3\frac{1}{16}$ inch triton blocks, is that a line of blocks entirely across the plate will, if laid on side, cut a 1-inch plate, or, if stood on end, will cut a $1\frac{1}{2}$-inch plate. Up to and including five rows, each additional row of blocks on side adds $\frac{1}{4}$ inch and each additional row of blocks on end adds $\frac{1}{2}$ inch to the thickness of the metal which can be cut.

259. **Steel bridges—Trusses.**—In destroying a bridge, try to cut the complete cross section. Charges should be placed in the upper and lower members of the trusses on both sides of the road. The best place for rupture is near the abutments where the chords have the least cross section, except in a cantilever bridge, which should be cut over the towers. By choosing the panel points for the location of the charges, they may easily be confined and tamped, and maximum results will be obtained with the smallest number of charges.

In the case of a heavy bridge, the amount of explosive carried will frequently be adequate to cut only one chord. In this case, the chor in tension is cut; that is, the lower chord, except in the case of a cantilever. Members in tension are nearly always made up of bars of rectangular cross section and should be cut at a point near the abutment where the least cross section of steel is used. A cantilever truss is destroyed by cutting the upper chord near the tower.

Figures 227 and 228 show the main members in both a through and deck railroad bridge, each of simple design.

Figures 229 to 237 show amounts of explosive and methods of placing same to destroy steel bridge members.

260. **Railroads.**—One block of triton laid against the web will take a 6-inch section out of a 90-pound rail that is spiked to ties. One block on top will not break it, but two will take out a 6-inch section.

In order to interrupt traffic, break as many rails as time will permit. It is a good plan to break each rail in two places, several feet apart. If the charges are placed on opposite sides of the rail, the fuses can be lighted at the same time, and the first charge that detonates will not displace the other.

Figure 238 shows a charge placed at the fishplate connections. Use four blocks of triton, placed close together with one cap, as shown. Earth should be used to tamp the charge. This charge will render useless two rails and their connection.

Figure 239 shows the location and quantity of a charge for destroying a switch.

Figures 240 and 241 give the same information for a frog and crossover, respectively.

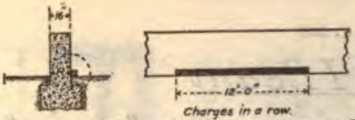
To destroy the railroad roadbed, the best location of the charge is in a culvert, such as are generally found under heavy fills. Table A, following, gives the charges required in such cases, and figure 242 shows the location of the charge. The charge can also be computed by the use of the formula for breeching charges (charts A, B, and C).

TABLE A.

LOADING FOR DEMOLITION OF RAILROAD ROADBED AT A CULVERT.

Distance of charge below roadbed.	Single - track line roadbed 15 feet wide.		Double-track line, roadbed 28 feet wide.			
	Number of charges.	Number of blocks of triton in charge.	Number of charges.	Distance C. to C. charges.	Number of blocks of triton in charge.	Total number of blocks of triton required.
Feet.				*Feet.*		
8.0	1	320	2	16.5	225	450
10.0	1	440	2	16.5	320	640
11.5	1	585	2	16.5	440	880
13.0	1	760	2	16.5	585	1,170

. **Blocking a tunnel** effectually interrupts railroad traffic. tunnel is lined with masonry or passes through sound rock, for a head-on collision at the center of the tunnel between a locomotive and another moving locomotive. In case of a ck tunnel, such a collision should occur on each track.



See Chart "D". C=5.0 K=.5 N=17 per yard.
Total = N = 4×17 = 68

Demolition of Masonry Wall.

Fig. 223

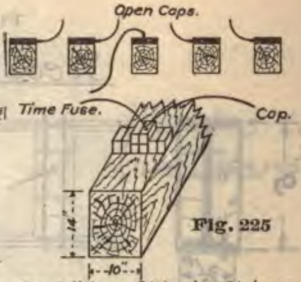
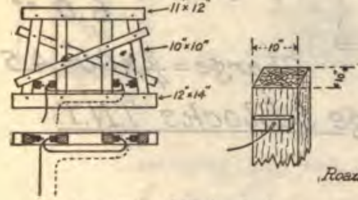


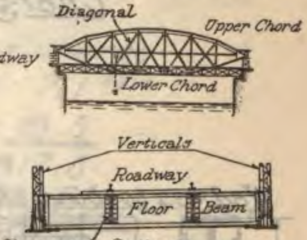
Fig. 225

Demolition of Wooden Stringer.



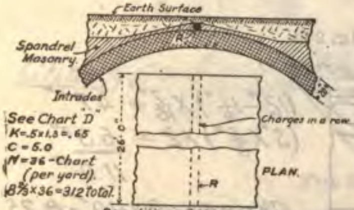
Demolition of Timber Bent

Fig. 224



Section aa
Through Bridge.

Fig. 227



See Chart "D"
K=.5×1.3=.65
C=5.0
N=36-Chart (per yard).
8⅔×36=312 total.

Demolition of Masonry Arch.

Fig. 222

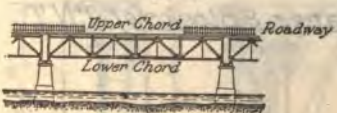


Fig. 228

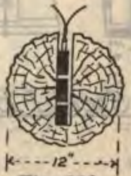


Fig. 226

Fig. 229

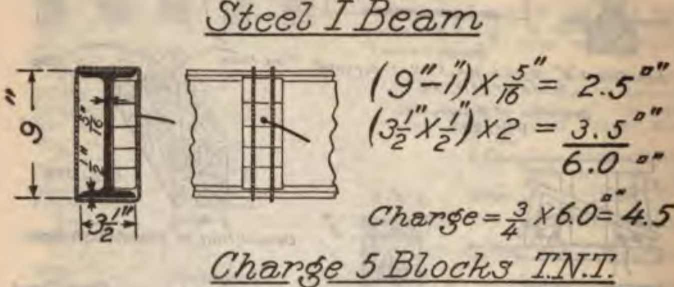


Fig. 230

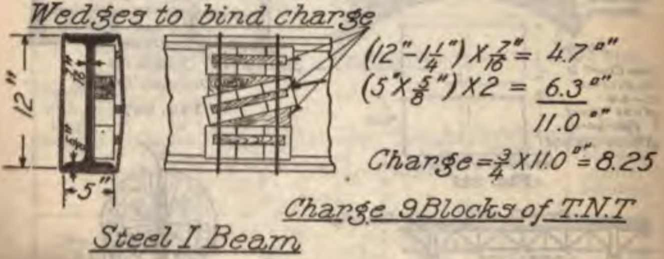
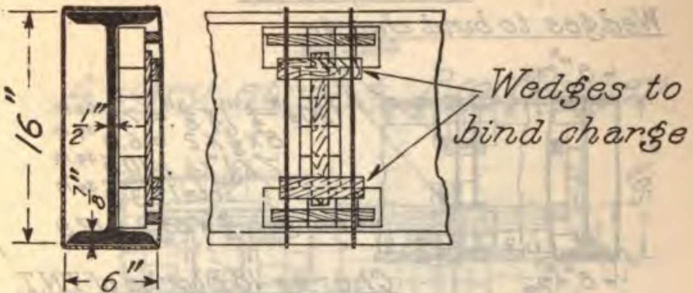


Fig. 231

Steel I Beam



Computation of charge

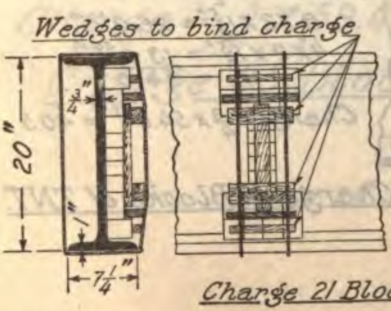
$$(16'' - 1\tfrac{3}{4}'') \times \tfrac{1}{2}'' = 7.1 \text{ sq.in.}$$

$$2'' \times 6'' \times \tfrac{7}{8}'' = \underline{10.5}$$

$$17.6$$

$$\underline{\text{Charge} = \tfrac{3}{4} \times 17.6 \text{ sq.in.} = 14 \text{ Blocks T.N.T.}}$$

Fig. 232



$$(20'' - 2'') \times \tfrac{3}{4}'' = 13.5\,\square''$$

$$(7\tfrac{1}{4}'' \times 1'') \times 2 = \underline{14.5\,\square''}$$

$$28.0\,\square''$$

$$\text{Charge} = \tfrac{3}{4} \times 28.0\,\square'' = 21.0$$

Charge 21 Blocks of T.N.T.

Fig. 233

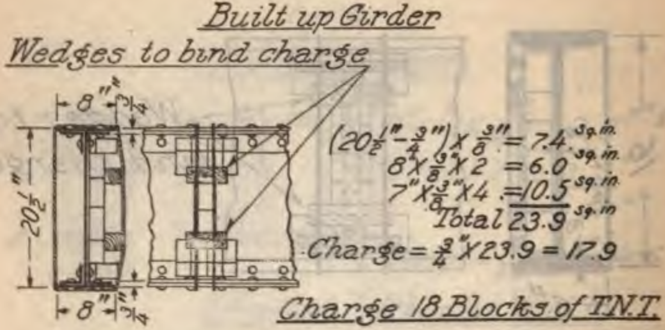

Built up Girder
Wedges to bind charge
8″
¾″
20½″
8″
¾″
(20½″ − ¾″) × ⅜″ = 7.4 sq.in.
8″ × ⅜″ × 2 = 6.0 sq.in.
7″ × ⅜″ × 4 = 10.5 sq.in.
Total 23.9 sq.in.
Charge = ¾″ × 23.9 = 17.9
Charge 18 Blocks of T.N.T.

Fig. 234

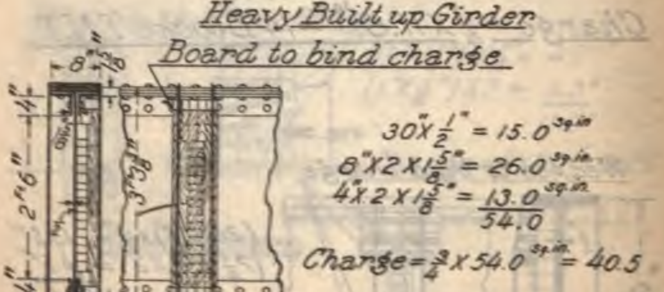
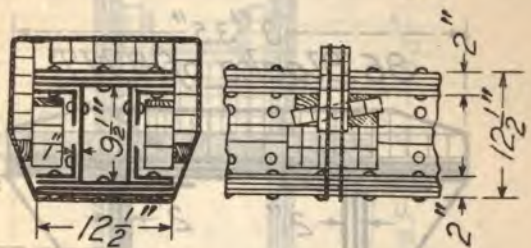

Heavy Built up Girder
Board to bind charge
8″
1⅝″
4″
2′6″
4″
1⅝″
3′⅜″
30″ × ½″ = 15.0 sq.in.
8″ × 2 × 1⅝″ = 26.0 sq.in.
4″ × 2 × 1⅝″ = 13.0 sq.in.
54.0
Charge = ¾ × 54.0 sq.in. = 40.5
Charge 41 Blocks of T.N.T.

Fig. 235

A very strong Box Girder



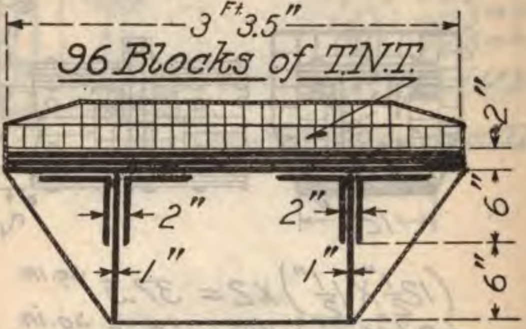
$$\left(12\tfrac{1}{2}'' \times 1\tfrac{1}{2}''\right) \times 2 = 37.5 \text{ sq. in.}$$
$$\left(9\tfrac{1}{2}'' \times \tfrac{1}{2}''\right) \times 2 = 9.5 \text{ sq. in.}$$
$$\left(6'' \times \tfrac{1}{2}''\right) \times 4 = \underline{12.0} \text{ sq. in.}$$
$$59.0 \text{ sq. in.}$$

$$\text{Charge} = \frac{3}{4} \times 59.0^{\text{ sq. in.}} = 44.25$$

Charge 45 Blocks of T.N.T.

Fig. 236

Upper Chord of a large Bridge



$$39.5'' \times 2'' = 79.0 \text{ sq.in.}$$

$$\left(12'' \times \tfrac{1}{2}''\right) \times 4 = 24.0 \text{ sq.in.}$$

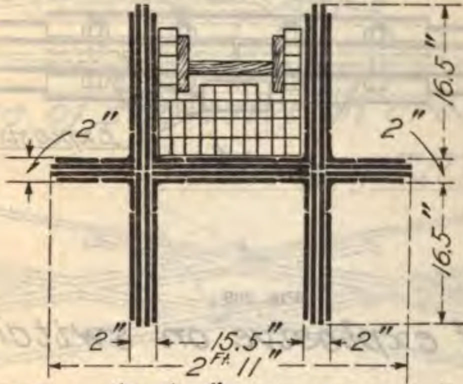
$$\left(12'' \times 1''\right) \times 2 = \underline{24.0} \text{ sq.in.}$$

$$127.0 \text{ sq.in}$$

$$\text{Charge} = \tfrac{3}{4} \times 127.0^{\text{sq.in.}} = 95.2 \text{ or } 96$$

Fig. 237

Chord of a very long Bridge



$$(16.5'' \times 2'') \times 4 = 132.0^{\text{sq.in.}}$$

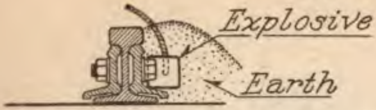
$$15.5'' \times 2'' = 31.0^{\text{sq.in.}}$$

$$(7.75'' \times 2'') \times 2 = \underline{31.0}^{\text{sq.in}}$$

$$194.0^{\text{sq.in.}}$$

$$\text{Charge} = \tfrac{3}{4} \times 194.0^{\text{sq.in.}} = 146 \text{ Blocks of T.N.T.}$$

Fig. 238



Use of Explosive for cutting R.R. rails

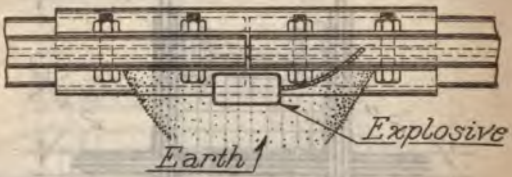


Fig. 239

Use of explosive on switches

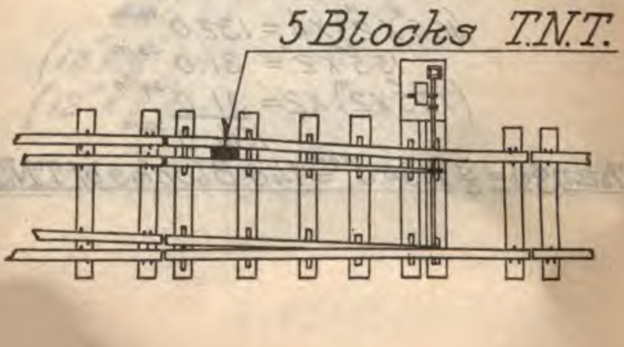


Fig. 240

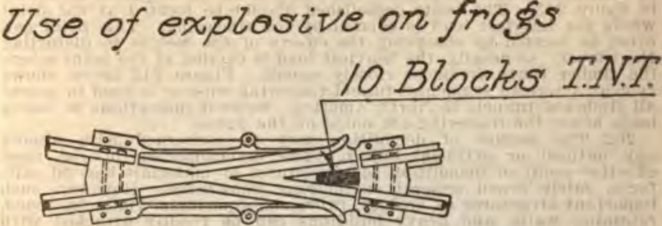


Fig. 241

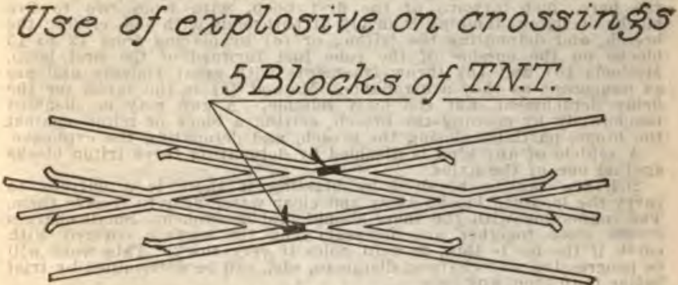
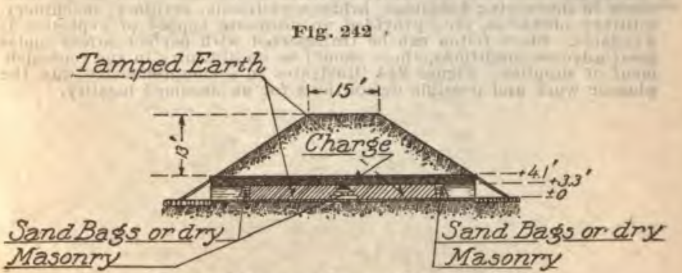


Fig. 242



Demolition of a railroad fill at a culvert.
Charge = 760 Blocks of T.N.T, see Table "D"

In case of a timbered tunnel, the timber bents may be demolished by cutting the vertical posts. The charges should be placed as shown in figure 243. The bents demolished should be located at the point where the heaviest load is carried by the timbering. This point can often be located by observing the effects of the weight in distorting the timber. Generally, the heaviest load is carried at the point where the timber bents are most closely spaced. Figure 243 below shows typical American segmental tunnel timbering such as is used in nearly all timbered tunnels in North America. Several indications of heavy loads above the timbering are noted on the figure.

262. The service of demolition may be concerned with almost any natural or artificial object. The determination of the most effective point of demolition for structures or materials blasted calls for a fairly broad general engineering knowledge. However, such important structures as bridges, railroads, aqueducts, viaducts, roads, retaining walls, and heavy buildings can be readily attacked with explosive by the application of the formula given.

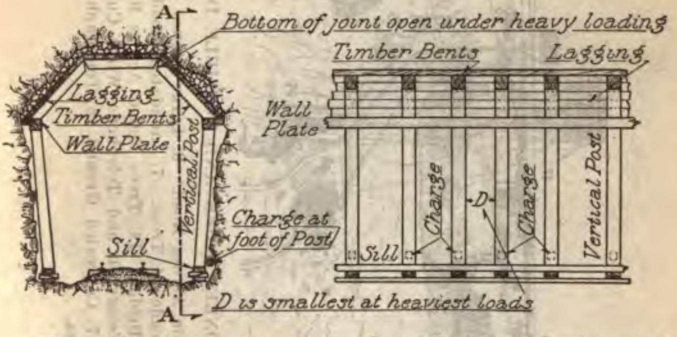
263. **Field guns and howitzers** may be destroyed (*a*) by placing a shell in the breech, closing the breech, and detonating a block of triton, tamped against the fuse of the shell; or (*b*) by filling the bore, just forward of the first hoop, with from two to five blocks of triton, tamping it firmly at both ends with sod, closing the breech, and detonating the triton; or (*c*) by placing from 12 to 15 blocks on the outside of the tube just forward of the first hoop. Methods (*a*) and (*b*) throw fragments with great violence and are as dangerous as they are reliable. Method (*c*) is the safest for the firing detachment, but the least reliable. A gun may be disabled temporarily by opening the breech, setting a block of triton against the hinge, partially closing the breech, and detonating the explosive.

A vehicle of any kind is disabled by detonating three triton blocks against one of the axles.

264. **Ice** can be removed by blasting if there is a current to carry the loosened blocks away and clear water near to receive them. The connection with the shore should first be broken. Small charges rather close together are necessary; on the surface covered with earth if the ice is thin, in drill holes if very thick. This work will be progressive, and charges, distances, etc., can be determined by trial better than from any rule.

266. By following the **instructions** above there will be no difficulty in destroying buildings, bridges, railroads, artillery, machinery, military obstacles, etc., provided an adequate supply of explosive is available. Since triton can be transported with perfect safety under most adverse conditions, there should be no difficulty in the replenishment of supplies. Figure 244 illustrates in a comprehensive way the pioneer work and possible demolitions for an assumed locality.

Fig. 243



Cross Section

Longitudinal Section A A

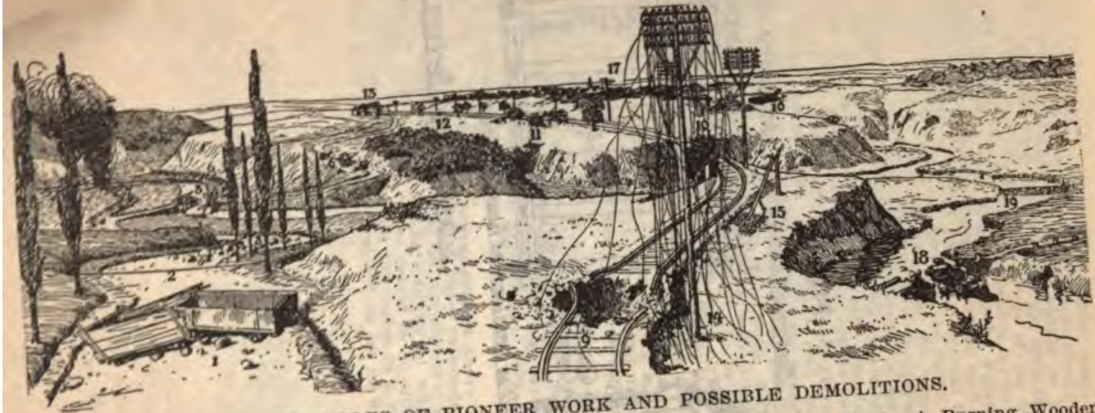


FIG. 244.—EXAMPLES OF PIONEER WORK AND POSSIBLE DEMOLITIONS.

Key: 1. Wagon Barricade. 2. Wire Cable Across Road. 3. Large Stones in Road. 4. Burning Wooden Bridge. 5. Demolished Iron Bridge. 6. Barricade of Trees. 7. Inundated Road. 8. Torn-up Road. 9. Rails Cut With Explosive. 10. Demolished Stone Bridge. 11. Trees Felled Across Road. 12. Concealed Injury to Rail. 13. Destroyed Railroad Station. 14. Telegraph and Telephone Wires Cut Down. 15. Telegraph Poles Cut Down. 16. Destroyed Cable Conduit. 17. Concealed Ground in Telegraph Wires. 18. Destroyed Stone Bridge. 19. Steel Net to Catch Floating Mines.

PART VI

ANIMAL TRANSPORTATION

PART VI—ANIMAL TRANSPORTATION.

1. **Animal transportation** for the Engineer service is divided into **wheel** and **pack** transportation. In wheel transportation the wagon is the unit, and each animal can haul, on a conservative estimate, 1,200 pounds gross or 700 pounds net load. In pack transportation the animal is the unit, and each can carry, also on a conservative estimate, 300 pounds gross or 225 pounds net load. A given quantity of freight carried on packs will require three times as many animals as would be necessary to carry it on wheels. The larger number of animals means a proportionate increase of the forage to be provided and in the labor of feeding, shoeing, etc. If, however, the country and season are favorable for grazing, the pack mule will get on without any forage, while the draft mule can not. Other disadvantages of pack service are that packages must be limited in size and weight much more closely than for wagons; long articles, as tent poles, can not conveniently be carried except by special construction, and loading of pack cargoes is an expert service which must be performed by a few trained men, while loading of wagons is work in which all can participate.

The great **advantage** of **pack transportation** is its mobility, and this consideration is often paramount. A good pack train, well handled, can make 2 miles to 1 of the best wagon trains on good roads and more on bad ones, and can besides go where there are no roads at all and where the country is so rough that roads could hardly be made and wagons could not pass them if they were made.

Wagon transportation should be used unless the country is impracticable or the rate of march too rapid for wheels. The permanent pack trains should be limited to the probable requirements of rapidly moving columns, and in those the baggage, etc., should be kept down to an absolute minimum. When great difficulties of wagon transportation are foreseen, the draft mules should be broken to pack service and enough aparejos carried in the train so that in case the wagons must be abandoned one-fourth to one-third of the loads may be placed on the mules and the march continued. The combination of harness and pack saddle which naturally suggests itself in this connection is not practicable. Such a combination would make a very poor harness and a worse pack saddle.

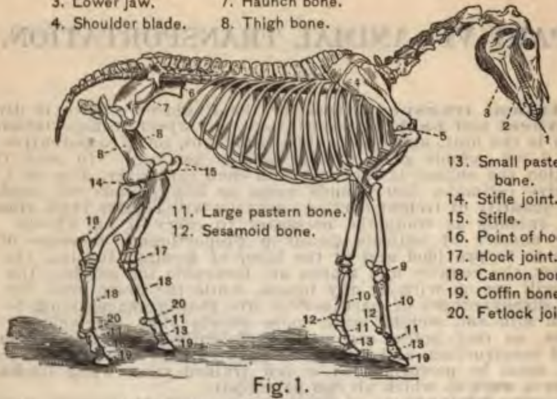
Mules were used interchangeably for draft and pack service on the Mexican boundary survey, and pack mules were put into harness in the China campaign.

2. **The mule** is the standard draft and pack animal of the United States service. He can best be described and understood by noting his points of difference from the horse, which he resembles so closely that it has not been found necessary to devote books to him particularly. The points of difference in conformation are mainly larger, thicker head, longer ears, and smaller feet, larger girth, shorter legs, and longer body. The relative disposition of bones and their angles are the same as for the horse. Figure 1 shows the skeleton and the names of the bones most likely to be the seat of injuries or disease. Figure 2 shows the mule's exterior conformation and the names of the regions into which it is divided.

Where extensive bogs are found, as in some parts of Alaska, horses are used for pack service, selection and breeding being conducted with a view to the maximum size of foot.

The mule is tougher and hardier than the horse, less subject disease or to inflammation from slight injuries, and usually yie

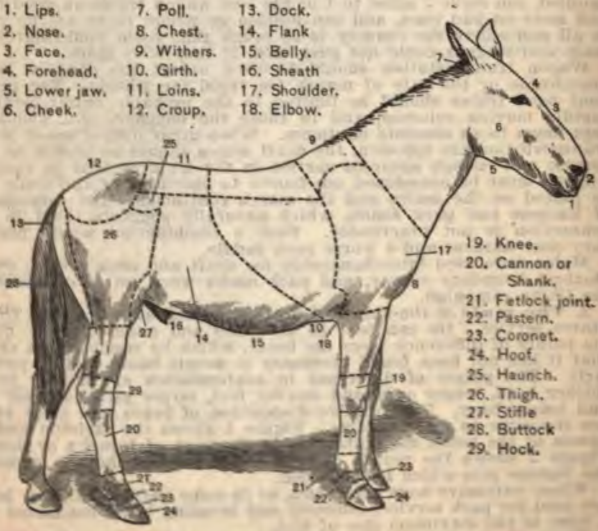
1. Incisor teeth.
2. Molar.
3. Lower jaw.
4. Shoulder blade.
5. Point of shoulder.
6. Haunch.
7. Haunch bone.
8. Thigh bone.
9. Knee bones.
10. Cannon bone.



11. Large pastern bone.
12. Sesamoid bone.
13. Small pastern bone.
14. Stifle joint.
15. Stifle.
16. Point of hock.
17. Hock joint.
18. Cannon bone.
19. Coffin bone.
20. Fetlock joint.

Fig. 1.

1. Lips.
2. Nose.
3. Face.
4. Forehead.
5. Lower jaw.
6. Cheek.
7. Poll.
8. Chest.
9. Withers.
10. Girth.
11. Loins.
12. Croup.
13. Dock.
14. Flank
15. Belly.
16. Sheath
17. Shoulder.
18. Elbow.



19. Knee.
20. Cannon or Shank.
21. Fetlock joint.
22. Pastern.
23. Coronet.
24. Hoof.
25. Haunch.
26. Thigh.
27. Stifle
28. Buttock
29. Hock.

Fig. 2.

more readily to treatment. He is nearly exempt from some common diseases of the horse, and especially from colds. In the field colic and kicks or other contusions are his principal troubles. When injured he does not exhibit lameness as quickly as the horse, and on this account needs more careful watching.

3. **Selection of mules.**—The cross between a jack and a mare is that most used and is the best. Of these, experience seems to indicate that mules resembling the sire—that is, small or medium sized, with strong markings, large ears, and small feet—are hardier, while those resembling the mare, good sized, smaller ears, larger feet, and no jack markings, are likely to show less endurance. Color does not seem to give any indication of constitution or disposition except as above noted. Good mules will be found in all colors. Mules for immediate use should not be taken under 4 years old. A mule sound and healty at 4 years should, with proper care and treatment, last until he is 18. There need be no distinction as to sex. Some experienced men prefer mares. Female mules are said to stand sea voyages better than males. Very large mules are not desirable.

A mule should be judged as to his **age, strength, endurance,** and **disposition. Indications of age** are not very precise as to exact years, but are clear enough as to the question whether the mule is too young or too old for service. At 4 years, which should be the minimum age, four of the six incisors in each jaw are permanent, and the others, the end ones, are temporary or milk teeth. The difference is plain, as the milk teeth are white and smaller than the others and are smooth outside and grooved inside, while the permanent teeth are grooved outside and smooth inside. In mules the tushes also appear at this age, smooth, straight, and pointed (fig. 3). At 5 years the remaining milk teeth are replaced by permanent ones, which latter, however, have no inside wall (fig. 4). At 6 years these teeth have the inside wall. At 7 years the ends of the incisors show wear and the tushes begin to appear blunted (fig. 5). From this stage on the age is a matter of judgment, based on the amount of wear of incisors and tushes and the angle of the incisors, which is obtuse in young animals and gradually changes to acute in very old ones (fig. 6). Other indications of age in the mule are the temples, full in the young and sunken in the old, and the wrinkles above the eyes, and gray hairs, both of which increase in number as the animal grows older.

The **indications of strength** are the size and build of the animal, especially of his legs. The fore legs should be set well apart at the shoulders and about equally wide at the feet and should appear straight when looked at from any direction. The hind legs should also set well apart and be parallel, and appear straight when looked at from behind. The angle of the pastern should be such that the middle line of the leg prolonged to the ground will just touch the heel when the animal is standing squarely and naturally on a smooth level surface.

The **indications of endurance** are principally the breadth and shape of the chest and the girth, both of which show the lung power on which endurance depends. The chest should be broad and muscular, and especially the breastbone should not be prominent. Looking at the animal from the side, the chest should appear to project distinctly in front of the fore legs. The girth, measured 6 to 9 inches in rear of the fore legs, should not be less than 1¼ times the height of the animal.

For **indications of disposition** look to the head and eye; the latter is especially a good index. Avoid mules with extra long heads; also those with hollow or dish faces. The eyes should be set well apart and stand out prominently. Eyes close together or sunken show a mean disposition. A good mule has a soft kindly look in his eye which is difficult to describe but is easily recognized. The ears should be mobile, and in young animals constantly moving; one pointing forward and one back is a good sign; laying both ears clear back when approached is a bad sign; but animals at rest and undisturbed frequently lay the ears back.

4. **Feeding.**—The ration for the mule is 9 pounds of oats or corn and 14 pounds of hay, the latter the same as for the horse, the former one-fourth less. Bran when issued is in lieu of grain, pound for pound. One hundred pounds of straw per month is allowed for bedding, or the same amount of hay if straw can not be had. The smaller grain ration is determined by the smaller average size of the mule and does not mean that he is a lighter eater than the horse or that he can do the same work with less nutrition. The ration is right for the *average* mule at *average* work. If he is extra large or is worked beyond this limit, he must have more grain or its equivalent in other food, or he will fall off in condition.

While the mule is less particular about his food than the horse, and will keep himself alive when a horse would starve, it is none the less important that his food should be clean and sound. He is particularly sensitive to sudden changes of diet even when the old food and the new is each good of its kind. Changes from grain to grass and the reverse, or from one kind of grain to another, should be made gradually. In addition to a proper quantity of food, the animal must have time to eat it. All of the hay and more than half of the grain should be fed at night, and the morning feed should be given at least an hour before hitching up. Pack mules frequently have the entire ration at night and are not fed at all in the morning. In the field the mules can be fed at the picket line by putting a layer of hay along the line, making a hollow or nest in front of each mule and pouring the grain into it. When no hay is fed and the ground is not dry and clean, lay down sacks on which to place the grain. Animals must be watched while feeding to prevent stealing from each other and waste by scattering grain or trampling it into the dirt.

Mules which are nearly exhausted or *pumped out* after a hard march will sometimes refuse to eat. Their food should be taken away and offered to them later, after they are rested a little, when they will usually take it.

Bran moistened with water to the consistency of brown sugar should be given occasionally, and always if there are signs of constipation. It may be given alone or mixed with a part ration of grain. It must be freshly mixed to make sure that it is not in the least sour. This and a little fresh grass, when it can be had, are sufficient usually to keep the bowels right. Purgatives should not be given except under the advice of a veterinarian or when constipation persists in spite of the simple remedies suggested. An ounce of nitrate of potash, or, if this can not be had, about a pint of wood ashes mixed with the bran mash, will slightly increase its laxative effect. Common salt has the same effect.

5. **Salt.**—Mules require a certain amount of salt, of which they are the best judges. The allowance is 2 ounces per week for each animal, which may be increased to 12 ounces per month, in the discretion of the commanding officer. In a corral, lumps of rock salt may be kept in boxes from which the mules will lick as much as they need. If glanders should make its appearance anywhere in the vicinity the use of these boxes should be discontinued and salt fed to the animals separately. This is best done in the bran mash. On the march salt must be fed in the same way. If the mules are found licking each other or the harness, or gnawing wagons or mangers it is an indication of lack of salt.

[illegible] the mules are herded for grazing at night, there should be a [illegible] to keep them from straggling. The bell horse should [illegible] but not picketed if it can be avoided. There should also [illegible] guard on duty. Pack animals are habitually trained to [illegible] horse, but draft mules are not. Horses have a peculiar [illegible] for the mule, and if one is turned into a corral with a [illegible] for two or three days they will follow him anywhere [illegible] induced to leave him. If a pack train is short of grain the bell horse should have a full ration, since he can not graze along the line of march while the pack mules can and do.

In open country a white or gray bell horse will make it possible to locate the train at a much greater distance. This may or may not be desirable, according to circumstances. This remark applies also to white or gray mules.

7. **Water.**—A mule requires from 4 to 6 gallons of water a day, depending on the season and his work. In an arid climate two or three times as much may be required. In an emergency he may be worked with what he will drink at one watering a day, but whenever possible he should be watered two or three times a day. In corrals there should be, except in freezing weather, a constant supply so that the animals can drink whenever they desire to do so. It is as important that the water be pure and wholesome as for any other animal. In fact, the mule is rather particular about his drinking water. In every herd some animals will refuse water which others drink and which appears to be good. No pains should be spared to find water which these animals will drink.

If the mules have had enough water at night, they often will not drink before starting in the morning. In such case **every effort must be made to get water at the end of the first hour's march.** Especial attention is required on this point, as the watering of draft mules on the road generally involves unhitching the teams or carrying the water in buckets, either of which operations causes trouble and delay and is likely to be neglected. In crossing a stream with soft bottom, if the mules are thirsty they should be watered before driving in, otherwise they may stop to drink and mire themselves or the wagon. A stream encountered at the end of a march should usually be crossed before going into camp.

8. **Diseases and treatment.**—The normal condition of a mule is indicated by a pulse of 34 to 38 per minute and a temperature of 99°. The pulse can best be taken inside the lower jaw or inside the fore leg just above the fetlock. Temperature is taken by a clinical thermometer inserted in the rectum for five minutes. Disease is almost always accompanied by an increase of temperature or pulse, or both. The pulse may run to 100 per minute or even more. A strong, full pulse of normal rate is a very good indication of freedom from disease or injury. The temperature in some diseases runs from 107° to 109°. In taking either temperature or pulse avoid exciting or worrying the animal. The normal rate of respiration when at rest is 12 per minute.

Apart from accidents, which will be frequent, and contagion, which will be infrequent, sick mules in the field will usually be the result of some neglect, as of feeding, watering, policing, or shoeing, or of abuse or overexertion. It is much easier and better to keep mules well by proper attention and treatment than to cure them when sick.

The diseases and injuries described below include those most likely to be encountered in field service, those in which effective treatment can be given by persons who are not skilled veterinarians, and those in which prompt action is necessary to prevent contagion.

Administration of medicines.—Liquid medicines are given as a drench. Put the liquid into a long-necked bottle without a shoulder and see that there are no sharp edges or projections about the mouth or neck. Raise the animal's head until the mouth is higher than the throat. Insert the neck of the bottle in the side of the mouth between the incisors and the molars. Point it toward the throat and allow the medicine to run out slowly and with intermissions if necessary.

Powders without disagreeable taste or odor may be dissolved in water and sprinkled on the feed or put into the drinking water.

Balls to contain dry medicines may be made by the addition of honey, sirup, or soap, using oil meal if necessary for required consistency. They should be about 2 inches long and ¾ inch in diameter, freshly made, and inclosed in tissue paper or gelatin capsules.

The mixture may be given a sticky consistency and placed on the tongue with a paddle or spoon. This form is called an **electuary.**

War Department Circular 9, series of 1907, provides that the mallein treatment as a preventive against generalized incipient glanders shall be administered quarterly in the United States and oftener in tropical countries.

The Quartermaster's Department supplies the mallein.

9. The following **table of veterinary supplies** is sufficient for ordinary requirements of field treatment:

Articles.	Designation.	Quantity for 100 animals.	Quantity for 200 animals.	Quantity for 300 animals.
Acid, boracic	Oz	4	6	8
Acid, carbolic	Oz	16	20	24
Aconite, fluid extract	Oz	1	2	3
Alcohol, grain	Gals	1	2	3
Aloes	Oz	20	24	32
Alum	Lbs	½	½	1
Camphor, gum	Lbs	1	1½	2
Calomel	Oz	2	4	6
Cosmoline	Lbs	4	8	12
Creolin	Lbs	2	4	6
Flaxseed meal	Lbs	25	30	40
Ginger, powdered	Lbs	1	2	3
Glycerin	Lbs	1	2	3
Iodoform	Oz	4	6	8
Iron, chloride, tincture	Oz	8	12	16
Lead, acetate	Lbs	1	2	3
Needles, surgeon's, assorted	Doz	½	¾	1
Oil, linseed, raw	Gals	2	3	4
Oil of turpentine	Gals	1	1½	2
Opium, tincture	Lbs	2	3	4
Potassium, nitrate	Lbs	3	4	6
Sulphur, powdered	Lbs	1	1	2
Sweet spirits of niter	Lbs	4	8	12
Tar, pine	Lbs	1	2	3
Witch-hazel, distilled	Qts	2	4	6
Zinc, sulphate	Lbs	1	2	3
Absorbent cotton	Lbs	2	3	4
Antiseptic gauze	Pkgs	2	2	3
Bandages, red flannel, 4 inches wide, 4 yards long	Doz	2	3	4
Bandages, white cotton, 4 inches wide, 4 yards long	Doz	4	6	8
Oakum	Lbs	10	15	20
Plaster, adhesive, 2 inches wide, 10 yards long	Rolls	1	1	2
Silk for ligatures, ordinary	Oz	½	½	¾
Silk for ligatures, heavy-braided	Oz	1	2	3
Soap, white castile	Lbs	10	15	20
Sponges, surgeon's	Lbs	1	2	3

tandard veterinary prescriptions:

und fluid=16 ounces=1 pint.

am solid or fluid=⅛ ounce.

tard silver dollar weighs $\frac{86}{100}$ apothecary's ounce; or $\frac{94}{100}$ ounce. By giving liberal measure it may be used as an it.

A 5-cent nickel may be used for a dram weight. If well worn it will be nearly right; if new, take scant measure. A balance can always be improvised.

Antiseptic or sterilizing dressings for external use only (Nos. 2 and 3 may be used on eyes, nose, and mouth):

1. Creolin 1 part, water 40 parts.
2. Carbolic acid 1 part, water 40 parts.
3. Boracic acid 1 part, water 20 parts.
4. Iodoform, dry, necessary quantity sprinkled on wound.
5. Boracic acid, dry, necessary quantity sprinkled on wound.
6. Sulphate of zinc 1 ounce, acetate of lead 1 ounce, water 1 quart. This is the well-known **white lotion.** A dram of carbolic acid may be added if a strong antiseptic is needed.

OINTMENTS.

7. Iodoform 1 part, cosmoline 6 parts.
8. Boracic acid 1 part, cosmoline 6 parts.
9. Carbolic acid 1 part, glycerin 6 parts.
10. Sulphur (if powdered) 2 drams, cosmoline 1 ounce.

LINIMENTS.

11. To relieve pain. Witch-hazel 2 ounces, spirits of camphor 2 ounces, laudanum 2 ounces.
12. Stimulating. Turpentine 2 ounces, spirits of ammonia 2 ounces, linseed oil 4 ounces.
13. Spirits of camphor 2 ounces, spirits of ammonia 2 ounces, turpentine 1½ ounces, water 1 pint.
14. Soap liniment. Castile soap 6 ounces, spirits of ammonia 6 ounces, spirits of camphor 2 ounces, alcohol and linseed oil each 1 pint.

MISCELLANEOUS.

15. Purge. Aloes 6 drams, calomel ½ dram, ginger 2 drams.
16. To stimulate the kidneys. Sweet spirits of niter 1 ounce, water 1 pint.
17. Founder powder. Nitrate of potash 4 ounces, gentian 4 drams.
18. Tonic. Gentian 2 drams, ginger 2 drams, flaxseed meal ½ dram.
19. Colic. Sweet spirits of niter 1 to 2 ounces, laudanum 1 to 4 ounces, ginger 2 drams.
20. To dress saddle and harness galls and to harden the skin. Alcohol 1 pint, water 1 pint. If the skin is abraded, mix with white of eggs to a paste and apply a thick coating.

Constipation.—Put the mule on a laxative diet—bran mashes, grass, or vegetables. Salt also has a slightly laxative effect.

Diarrhoea.—Usually results from two laxative diet or exposure. Put the animal on dry feed without salt and keep dry and warm. Do not work more than necessary. In aggravated cases give ½ pint of raw linseed oil or 1 dram of powdered opium.

Spasmodic colic.—The animal appears to be in distress, looks around at its flanks, paws, kicks at its belly, attempts to evacuate the bowels and to pass urine. Pulse and respiration accelerated. The attacks are intermittent and between them the animal returns to apparently normal condition.

Give a drench of 1 pint of raw linseed oil, and prescription No. 19. If the animal has not been overfed and the case is light, 1 dram of powdered ginger mixed in water will do. Give ample room to move about.

Flatulent colic.—More serious and less frequent than the former; pain apparently less severe but continuous; animal unsteady on its legs; extremities cold; excessive distention of abdomen.

Give No. 19 full strength, repeating at hour intervals until relieved. In severe cases it is necessary to puncture the animal to relie [illegible] distention. The puncture is made in the right flank in the bounded by the backbone, the hip bone, and the last rib, and at the point of greatest distention. The puncture is made with the trocar directed downward and inward. Leave the canula in the opening [illegible]. This operation should be done by a veterinarian or farrier.

Poll evil.—An abscess on top of the head immediately behind the ears. Troublesome mainly from its unfavorable situation for treatment. Keep bowels open and reduce inflammation by applications of hot water. After pus has formed, open clear to the bottom so that the pus readily can run out from the lowest part. Poultice and keep open until discharge of pus has entirely stopped. Use antiseptic dressings [illegible]

Strangles.—An inflammation of the glands of the throat and neck, resulting in the formation of an abscess. Good care and soft food, varied as much as possible to stimulate the appetite, are all that is required until the tumor heads, when it should be freely opened and drained until it is free of pus.

Glanders.—A yellowish, sticky discharge from the nose, with ulcers inside the nostrils, at first distinct, then with ragged edges and finally confluent; enlargement and hardening of one or both glands below the jaws; staring coat; difficult respiration; extreme debility and profuse perspiration on the slightest exertion; fetid odor from nostrils in advanced cases. The disease is contagious and incurable. As soon as suspected the animal must be isolated, and when the disease is recognized he should be killed and burned or deeply buried. All grooming and other implements used about the animal should be destroyed and his surroundings thoroughly disinfected. Attendants should use great care to avoid contagion in handling suspected cases. The hands should be free from cracks or sores, and after touching the animal should be well washed with a little carbolic acid in the water.

Farcy.—A different and milder manifestation of the same poison as in glanders. Ulcers appear on head, body, or legs; they are commonly called **farcy buds** or **buttons.** When the legs are affected they swell, and the buds are usually below the knees or hocks, oftenest in a line down the front of the foreleg, beginnig at top and running to the bottom. In the early stage the buds are hard lumps beneath the skin. Later they enlarge and suppurate through the skin. Before this condition is reached the animal should be killed.

Surra.—A disease resembling glanders, prevalent in the Philippine Islands. It is probably a wound disease, caused by contact of the infectious agent with a wounded surface, either skin or mucous membrane. At first loss of appetite, constipation, fever, and thirst; later a dropsical swelling, usually beginning around the belly and immediately or quickly extending to legs and feet, with rapid and extreme emaciation. Sometimes the submaxillary glands are involved, with discharge from the nose resembling that of glanders. A very characteristic symptom is dragging the hind feet in walking. The disease runs from 3 to 4 weeks and sometimes longer. No remedy is as yet known. Isolate as soon as suspected, and, when the diagnosis is certain, destroy the animal and burn or bury the carcass.

Isolation hospitals and corrals should be half a mile from other corrals. No nonisolated animals should be allowed to approach them to bring visitors or supplies, which should be conveyed by other

nimals should be carefully examined and all abrasions of skin
s membrane should be protected from biting insects by local
ns.

d and sick animals should be protected from biting insects,
s, by screens, smudges, or washes, and carcasses should
tected until burned or buried.

forts should be made to exterminate biting insects

Where surra is or has been prevalent, allow no grazing and avoid all green forage, especially from marshy or overflowed ground. The disease is more prevalent in wet places and wet weather.

Mange.—Small pustules form on the skin, usually beginning at the roots of mane and tail. The discharges form a crust, under which the hair loosens and falls out. The disease is contagious, and animals affected must be isolated and usual precautions taken. Cleanse the affected parts thoroughly with soap and water and dress with No. 2. If the skin is affected over a large surface, only a part of it should be gone over with the carbolic solution each day, to avoid carbolic-acid poisoning. It is better in such cases to substitute No. 1, which may be used with impunity.

Scratches.—An inflamed condition of the skin of the heel with crusts giving a watery discharge. Caused by exposure to wet and cold, sometimes by trimming the fetlocks. Keep the parts dry and clean. Wash, if at all, with warm water and castile soap and dry thoroughly after washing. If the skin is unbroken, use fresh lard and vaseline; dust with powdered alum twice a day. If the skin is cracked, use No. 10. A dry place for the animal to stand is necessary to a cure.

Thrush.—A disease of the frog, usually behind, accompanied by an offensive discharge. It results from uncleanliness. Keep the frog clean and dry; pare away ragged parts and open the cracks to facilitate discharge; dust with calomel and dress with iodoform or pine tar.

Laminitis or **founder.**—An acute inflammation of the processes which connect the wall of the hoof with the coffin bone. More common in the front feet; very painful and causes extreme lameness and stiffness with much heat in the foot. Overexertion, indigestion, and *watering when heated* are most frequent causes. The animal can scarcely be induced to move, and tries to take the weight off the toes by standing on the heels, or, if the fore feet only are affected, by drawing the hind feet forward under the body.

Give laxative diet and plenty of water, remove the shoes, and give the animal a soft footing which will throw as much weight as possible on the sole and frog. In the field a good plan is to make a slight depression in the ground, fill it with water, and let the mule stand with his fore feet in the mud. Give No. 17.

Lockjaw.—Induced by pricking the foot with rusty iron, or by punctured wounds. The disease is caused by a microbe which thrives in rich soils, as of highly cultivated gardens and in the Tropics. Common in the Philippines as a result of punctured wounds.

There is difficulty in swallowing and rigidity of the limbs; ears erect and to the front; nostrils dilated; legs spread apart and tail persistently held erect. General muscular rigidity; obstinate constipation and torpidity of the liver. The climax usually comes in three or four days.

Search for the exciting cause, and if found to be a wound of any kind, treat it. Give a strong purgative and 2 to 3 drams solid extract of belladonna three times a day. Give liquid food—gruels—and have clean water in reach of the animal at all times. Give rest and quiet in a darkened stall. During convalescence give laxative nutritious foods and tonics, as No. 18.

Rope burns.—Abrasion of the skin under the fetlock by rubbing against a rope. Very frequent, especially with mules not accustomed to being tethered or picketed. If not severe, cleanse with soap and apply ointments 7, 8, or 9, or tar, or any kind of clean grease. For severe cases use the same treatment and bandage.

Pricking the foot.—This may result from picking up a nail or from one improperly driven in the shoe. If the point of injury can not be seen, locate it by pressure. The mule will flinch when the sore spot is touched. If suppuration has not set in, clean the part, treat it with antiseptic, and stop the orifice with a plug of sterilized material. If pus has formed, a free exit for it must be provided and maintained. It may be necessary to cut away a consider amount of horn to do this.

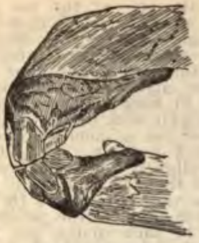


Fig. 3, 4 years

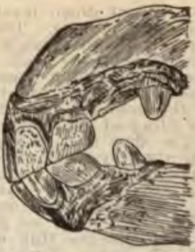


Fig. 4, 5 years.

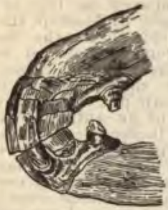


Fig. 5, 7 years.

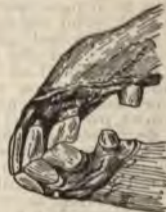


Fig. 6, very old.

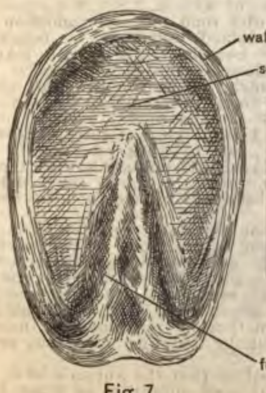


Fig. 7

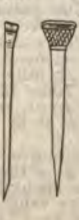


Fig. 9

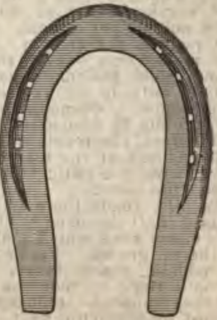


Fig. 8
Mule shoe, not fitted.

should then be cut down level with the sole at the toe and left a little longer at the heel. The heel wears a little under the shoe and will rarely require much cutting. The rasp is used to cross level the bottom of the wall, which should be accurately done, so that the mule will stand square on the shoe. The shoe is now to be fitted accurately, so that its outer edge will follow the circumference of the hoof all around. The fit must be made close enough so that no filing of the sides of the wall will be necessary to complete it. The shoe is then applied hot for a moment, and the high points indicated by burning are worked down. The shoe should then be applied hot long enough to slightly sear the lower surface of the wall, but no longer. It should then be cooled and nailed on. In nailing, begin with the front or toe nails and drive them in their order to the rear. After all are driven, cut off the points near the hoof, rasp the clinches thin enough to turn easily, but do not let the rasp cut the horn. Turn the clinches down snug, but do not try to drive them into the hoof, nor use a file on them to smooth up.

Management of vicious mules.—Ordinary cases can be handled by lifting the foot with a strap or rope. Take hold of the pastern and be sure that the rope can not slide so far as to cause a burn. For a hind foot, draw forward between the legs or to a collar; for a fore foot, bend sharply at the knee and strap the pastern to the upper leg. For bad cases in the field, throw the mule and shoe him while down. For the shop, construct a frame of stout timbers in which he can be tied in every direction by ropes, straps, or canvas bands. Twitches on the ears should never be used. If absolutely necessary to control the animal, put a twitch on the nose.

12. **Animal power.**—The capacity of an animal to exert a tractive effort decreases as speed and time increase. As a basis, it may be assumed that an average draft mule can pull on a level 80 pounds at 2½ miles an hour for 10 hours every day, or, in other words, can pull 80 pounds over 25 miles of average level roads every day. If a pull of 160 pounds is required, it can be made over 12½ miles a day only, the lesser distance being covered by a slower gait or longer rests, or, as is usually the case, partly by each. An animal can exert two and one-half times the normal pull for a few minutes at a time, and five times for a few seconds, provided in each case the demand is not repeated too frequently.

The **load which can be hauled on any pull** depends mainly on the kind and condition of the road and a little on the wagon, especially as to width of tire and size of wheels. For the standard Army wagon and on a level average dirt road in good condition the load corresponding to 80 pounds standard pull may be taken at 1,000 pounds per animal. Of this, 300 pounds will be wagon, leaving 700 pounds net freight. Any reduction of this load to lessen the pull must come out of the 700 pounds. To reduce the pull to 40 pounds, 500 pounds must be taken from the freight, leaving 200 pounds only to be hauled. This 200 pounds pulled over 25 miles would equal 5,000 pounds pulled over 1 mile, while if the full load of 700 pounds is hauled over 12½ miles, which can be done with the same effort, the result equals 700 × 12½ = 8,750 pounds hauled 1 mile. If the length of the march is fixed, the animals can be relieved only by reducing the pull; otherwise it is better to relieve them by shortening the march.

On hilly roads there is no traction on the down grades and an in-
gait is usually taken without appreciable extra exertion.
s time which may be spent in rests, allowing greater effort
grades. Up to 8 per cent grade, the load can be retained
the distance. Up to 3 per cent grade, the distance can
d by reducing the pull. Above 8 per cent, both pull and
be reduced. The reduction of pull may be accom-
ing part of the freight, by doubling up teams, or by
dragropes.

ased on the supposition that the animals have the
y and remain in as good condition as when they

started. In emergencies they can do more work than indicated, but will go off in condition and some will give out entirely. In campaign, animals are overworked as a rule, and finish in very poor condition. This is necessary because adequate transportation is rarely available and what there is must be worked at a killing rate. When marches are intermittent, mules may be pushed, since what they lose in two or three days' overwork can be made up by a week's rest with good care, and they will be fit when again required.

The following are the **weights and normal loads** of some Army wagons:

	Weight.	Maximum net load.	Gross load.
	Pounds.	*Pounds.*	*Pounds.*
Army six	1,950	4,000	5,950
Escort	1,500	3,000	4,500
Ambulance	1,450	....	....
Dougherty	1,375	....	....
Engineer tool wagon	2,200 to 2,600	2,500	4,700 to 5,100
Pontoon tool wagon	1,700	2,100	3,800
Bridge train, light	1,750	1,856 to 2,060	3,606 to 3,810
Bridge train, heavy	1,750 to 2,200	2,280 to 2,900	4,030 to 5,100

Harness.—The harness supplied for heavy draft is of three kinds, known as **army wagon harness, 4-mule ambulance and wagon harness,** and **ambulance harness.** The first is distinguished by the absence of a saddle; by its breeching, which is of flat leather unstitched, and its traces, which are of chain throughout and pass through leather pipes to prevent chafing. The second is distinguished by its traces, which are of leather to the breeching, with chain extensions. The third has all leather traces. The second, or ambulance and wagon harness, is most suitable for Engineer transportation.

Most 6-mule teams are driven with a jerk line, the driver riding the near wheeler (fig. 10). Four-mule teams in the bridge train are driven in the same way. All other 4-mule teams are driven with lines from a seat on the wagon (fig. 11). The 6-mule harness includes a riding saddle, jerk line, check rein, jockey stick, and blacksnake whip. A set of 4-mule harness includes a pair of wheel lines, a pair of lead lines, a whipstock, and lash.

Proper **fitting of the harness** is very important. The bridle should be loosely fitted, the crownpiece and throatlatch not too tight; the brow band in the right place; the cheek pieces so adjusted that the bit will hang in the mouth just clear of the angle of the lips, not far from it and not touching it, especially not drawing it up into wrinkles. The bit should be of the right length for the width of the jaw. Less damage will be done, however, if the bit is too long than if too short. If the bit tends to irritate the mule's mouth at the ends, relief may be given by putting a large leather washer around the bit inside the ring. The blinds must be so adjusted as not to touch the eyelashes.

The fit of the collar requires close attention. If it is too small, it will cut off the wind; if too large, it is likely to make the shoulders sore. When the collar is on and adjusted, there should be room to insert the open hand between the bottom of the collar and the

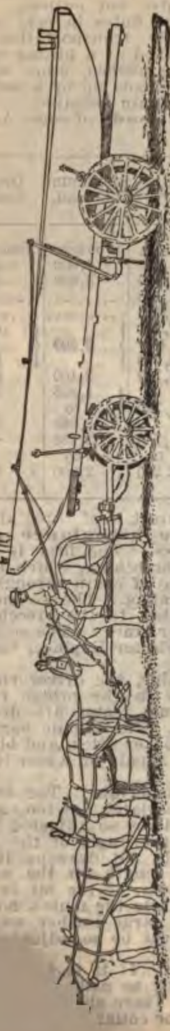


Fig. 10, Six-mule jerk-line and ponton wagon.

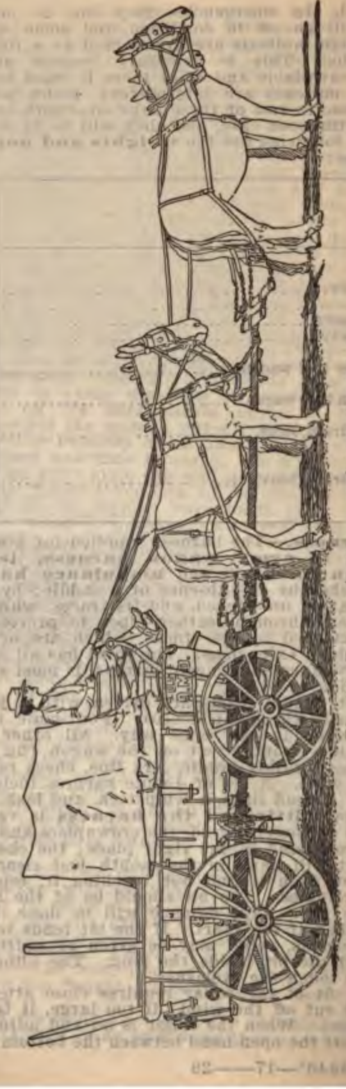


Fig. 11, Four-mule team and escort wagon.

pipe, and not much more. Collars should always be buckled when off the mules. A collar which is the right size but not the right shape can be improved by soaking it in water and putting it on wet. A day's work in the rain will produce the same result. The undersurface of the collar should be kept clean and soft. Do not scrape it, but rub or wash it clean. The same remark applies to every part of the harness which touches the mule's skin. Cleaning the outside of a harness is good for the harness only; cleaning the inside is good for both mule and harness. The driver should be provided with two or more small pads of sheep skin with thongs attached. If the skin is abraded by the harness, two of these pads may be lashed to the underside, one on each side of the sore, and will afford relief until the march is over and regular treatment can be applied. The hames should be so adjusted to fit the collar closely without pinching it out of shape.

To clean harness, hang a set on a pole or line; wet a sponge in clean water and rub gently over the harness until the dirt is softened. Rinse the sponge frequently and renew the water as often as necessary. Next rub the sponge on the harness soap until a good lather is formed. Give the harness a thorough coating of it and continue the rubbing until all dirt is removed. It may be necessary to use a thin piece of wood to get some spots clean. When the harness is clean rub up a very thick lather and coat the leather evenly with it, allowing it to dry without rubbing. After the lather has been absorbed and the leather is dry, dip a small clean sponge in harness dressing and touch the harness lightly, rubbing just enough to spread the dressing evenly.

If the leather is very hard, after cleaning as above, take a pint of neat's-foot oil and a teaspoonful of lampblack to each single set. Mix thoroughly until a black glossy appearance is produced and apply an even coat with a small sponge, rubbing it well in. In cold weather warm the oil enough to make it flow freely, but do not let it get hot. After thoroughly dry, apply harness dressing as above described.

Harness should be looked over carefully every day. If stitches are broken, leather worn or cut, or any metal parts cracked or broken, have the defect remedied at once. If stitches are taken, be careful not to leave knots on the inner surface of the harness. Fasten at beginning and end by drop stitches. In the field provide supports for the harness and keep it off the ground when not in use.

The following allowances of materials for the **repair** and **preservation** of **harness** are prescribed in addition to those listed in paragraph 14, as a part of the equipment of an escort wagon and ambulance:

For each double set of quartermaster harness; 1 leather, harness, black, pound; ⅒ rivets and burrs, copper, pound; 2 thread, saddler's, ounces; 2 wax, saddler's, ounces.

For every 20 double sets of quartermaster harness: 1 needles, Glover, paper; 2 needles, harness, No. 2, papers; 2 needles, harness, No. 3, papers; 2 needles, harness, No. 4, papers.

The following sizes of rivets and thread are required: Rivets and burrs, copper, No. 8, 1¼-inch; No. 9, ½-inch; No. 9, 1-inch; No. 12, ½-inch. The rate of consumption, by weight, of each of these sizes is ordinarily the same. Thread, saddler's, Nos. 3 and 10, the same amount of each.

Loops, halter, 1¼ inches	2 dozen.
Open links, No. 2 iron, 10 per foot	50
Oil, neat's-foot	10 gallons.
Rings, No. 2, 1¾ and 2 inches	2 dozen each.
Rings, breeching, No. 3, 3½, and 4 inches	2 dozen each.
Rings, D, 1½ inches	1 dozen.
Rings, line, 1¾ inches	2 dozen.
Rivets and burrs, copper, No. 12, ¾ and ⅜ inch, No. 8, ½ and ⅝ inch	1 pound each.
Slides, breast, 1½ inches	1 dozen.
Snaps, harness, ⅞ and 1 inch	2 dozen each.
Snaps, harness, 1¼ and 1½ inches	1 dozen each.
Soap, harness	100 pounds.

Sponges, coarse	5 pounds.
Squares, halter, $1\frac{1}{2}$ by $1\frac{1}{4}$ inches	3 dozen.
Tacks, 4, 8, and 12 ounce	$\frac{1}{2}$ dozen papers each.
Thread, shoe, Barbour's Nos. 3 and 10, white	1 pound each.
Toggles, trace	6 dozen.
Wax, saddler's, black, spring, summer, or winter	1 pound.

14. **Wagons.**—For general freighting, the wagons in use in the United States service are the **army six,** weighing 1,950 pounds, and carrying 4,000 pounds, with a 6-mule jerk-line team, and the **escort** (fig. 11), weighing 1,500 pounds and carrying 3,000 pounds with a four-line team. The army six-wagon is no longer furnished by Quartermaster Corps for use in campaigning, being limited to use in garrisons.

The bridge equipage is carried on two types of wagons, the **ponton wagon** (fig. 10), weighing 2,200 pounds, and carrying 2,900 pounds, and the **chess wagon**, weighing 1,750 pounds, and carrying 2,300 to 2,700 pounds. The ponton wagon is used for the wooden ponton. The chess wagon is used for all other bridge loads.

To **keep a wagon in order** it is only necessary to keep all nuts tightened, the wheels greased, and to wash the mud off when opportunity offers. Four to six pounds of axle grease per wagon per month will be ample. In dry sand wagons in constant service should be greased daily. On hard roads they should be greased every 40 to 50 miles. Always clean off the old grease before putting on the new. In washing use as much water and as little rubbing as possible.

The following are spare parts and accessories for each escort wagon, ambulance and accompanying teams:

Escort wagon and harness, complete set—

Wagon, escort (includes running gear; wagon body; 1 tongue; 1 doubletree; 1 lead bar; 4 singletrees; 6 bows; 2 chains, lock; 1 wagon cover; 1 jockey box and 1 oscillating tool box, each with padlock and key; 1 driver's seat; and 1 axle wrench). Total weight, 2,033 pounds.

	Where carried.	Number.
Wagon equipment.		
Wagon parts, extra (total weight, 106 pounds)—		
Blocks, brake	In oscillating tool box	2
Bolt, king	do	1
Bolts, tire—		
$\frac{1}{4}$ by $2\frac{3}{4}$ inches	do	1
$\frac{1}{4}$ by 3 inches	do	5
Bolts, wagon—		
$\frac{1}{4}$ by $1\frac{1}{2}$ inches	do	2
$\frac{5}{16}$ by $1\frac{3}{4}$ inches	do	2
$\frac{5}{16}$ by 2 inches	do	1
$\frac{5}{16}$ by $2\frac{1}{2}$ inches	do	2
$\frac{3}{8}$ by 3 inches	do	2
by 11 inches	do	1
y 4 inches	do	4
open	do	3
cle	do	2
[illegible]	On left side of wagon body	1
Iron—		
y $1\frac{1}{2}$ inches	In oscillating tool box	6
y $1\frac{1}{2}$ inches	do	4
e	On left side of wagon body	1
—		
ouble	Bolted to coupling pole	1
Single	In oscillating tool box	1

	Where carried.	Number.
Wagon equipment—Continued.		
Wagon accessories (total weight, 83 pounds)—		
Ax and helve	.....do	1
Bags, nose	.....do	4
Brush, horse	.....do	1
Bucket, galvanized iron	.....do	1
Comb, curry	.....do	1
Globe, lantern	In lantern, in oscillating tool box.	1
Grease, axle, pounds	In oscillating tool box	4
Halters and straps	.....do	4
Lantern frame, combination	.....do	1
Pickax and helve	.....do	1
Rope, ⅜-inch, feet	.....do	150
Spade	.....do	1
Whip	In socket	1
Wick, lantern	In lantern, in oscillating tool box.	1
Wrench, monkey	In oscillating tool box	1
Twine, ball	.....do	1
(For winter use, when especially authorized, 1 blanket-lined cover for each mule.)		
Harness:		
Lead, s. s. (72 pounds)	On mules	2
Wheel, s. s. (90 pounds)	.....do	2
Harness equipment—		
Harness parts, extra (total weight, 8½ pounds)—		
Buckles—		
¾-inch	In jockey box	1
⅞-inch	.....do	1
1-inch	.....do	1
2-inch	.....do	1
Clips, trace	In oscillating tool box	2
Hames	.....do	2
Rings—		
¾-inch	In jockey box	1
1-inch	.....do	1
1½-inch	.....do	1
2-inch	.....do	1
Snaps—		
1-inch	.....do	1
1¼-inch	.....do	1
2-inch	.....do	1
Straps, hame	In oscillating tool box	3
Harness accessories (total weight, 6 pounds)—		
Oil, neat's-foot, gallon	.....do	½
Soap, harness, pound	.....do	1
Sponge	.....do	1
Wire, stove, spool	In jockey box	1

Wheels, extra.—One wagon of each regimental field train, preferably the most lightly laden grain wagon, will be equipped with one extra hind wheel in addition to the usual wagon equipment.

Lists of spare parts for bridge wagons are given in Ponton Manual.

15. **Pack saddles.**—The adopted pack saddle is of the Spanish type, and is commonly called by its Spanish name **aparejo.** Its principal parts are the **body,** the **cover,** the **cincha,** and the **crupper.** These parts have subdivisions, which are less important. The accessories added to the above to make the **aparejo complete,** are the **corona,** the **blanket,** the **lash rope** with its **cincha,** the **sling ropes,** the **lair ropes,** and the **mantas** or pack covers.

The body of the aparejo consists of 2 pieces of heavy leather 24 inches wide by 58, 60, or 62 inches long, sewed together at the edges and across the middle of the length, forming 2 pouches, into which moss or hay is stuffed to form pads fitting the contour of the animal on either side of the backbone. In the American form, the pads are given a peculiar elastic stiffness by means of ribs of wood or metal extending from a saddle piece at the top of each pouch to a boot piece at the bottom. These ribs are stiffer at the front and more flexible at the back, varying uniformly between. They convert each pad into an elastic lever, by which the pull of the cincha on the bottom acts to raise the aparejo and its load from the backbone, while the stuffing distributes the load uniformly over a large space on the ribs. The stuffing is introduced through a handhole in the middle of the underside of each pad, through which it is always accessible, and the finest art of the packer consists in fitting the pads to the shape of the particular animal which is to carry the aparejo, and keeping them so regardless of changes in the animal's condition by shifting, removing, or renewing the stuffing. If a bunch rises on the animal, it can be worked down by taking out stuffing immediately over it so as to take off the pressure at that point. Determine the proper point by wetting the top of the bunch and laying the aparejo on the mule. Aparejos and mules are numbered and the same pack is always on the same mule.

The **function of the crupper** is not what would naturally be expected. If the aparejo is properly set up and fitted there will be no tendency to move back or forward. The crupper is in reality a steadying lever to keep the aparejo from rocking fore and aft as the mule travels. For this purpose, the dock piece is large, smooth, and soft, and the crupper is wide, stiff, and firmly laced to the body. The crupper is adjustable in length, and must be accurately fitted so that when the aparejo is in its proper place the dock piece will ride between tail and dock without pressing on either.

The **cover** is permanently attached to the body and may be considered a part of it.

The **cincha** is of heavy canvas, doubled, and 10 inches wide. It is long enough to reach from the near boot under the mule and around the aparejo to a little beyond the middle. The ends are connected by the **latigo,** or **cincha strap.**

The **corona** is a pad usually of several thicknesses of blanket, with a number or design which identifies the pack. It is important that the corona shall not be separated from its aparejo.

Off the mules the aparejos are placed in a row on the ground or on skids, standing on their boots. The cincha, folded with the latigo inside, rests on the aparejo. The crupper is turned so that the dock piece rests on the cincha. The corona is placed on top of all. Canvas covers are stretched over the line of aparejos and tied down. The line of aparejos so arranged is usually referred to as **the rigging.**

Each packer is provided with a **blind.** The mules are trained to stand perfectly still when blinded, and if it is necessary to move a mule even by a step, the blind should be lifted.

To place the aparejo on the mule the corona is first put moothly on, followed by the blanket folded to 6 thicknesses. The ejo is then put on slightly in rear of its place. The crupper is ed, the dock piece adjusted, the aparejo settled to its place, and cincha unfolded, placed, and tightened. Never put on or adjust ck *with* the mule's head uphill.

16. **Loads** are divided into **side packs** and **top packs.** Side packs should be of approximately equal weight and size. A keg of paint on one side and an equal weight of oakum on the other do not make a proper load. Side packs should not be longer than 30 inches, wider than 20 inches, nor deeper than 12 inches. If the side packs do not fill out a load, the rest is placed between them as a top pack. Articles which by their size or shape are not suitable for side packs are carried on top. The center of gravity of the entire load should be below the top of the saddle, and the lower the better. For miscellaneous cargoes, the freight is made up into side and top packs, each wrapped in a **manta,** or canvas cover, and tied, or **laired up** with **lair ropes.** If a pack contains articles of different weights, place the heaviest at the bottom. The side packs are slung across the aparejo by the **sling ropes** and lashed on with the **lash rope** and **cincha** in the form of the **diamond hitch** (figs. 34 to 38.) Such a load must remain unbroken until the end of the march.

17. **Care and preservation.**—All parts of the rigging should be kept clean and the leather parts soft and pliable. The materials and methods given for harness may be adapted.

18. In **taking off lashed packs,** the lash rope is removed; its cincha laid on the ground in the middle of the line to be occupied. The lash rope is coiled down on the cincha and its end stretched out 10 feet to one side. The sling rope is then unfastened, the packs dropped from the aparejo and laid on the lash rope lengthwise with the cincha. The sling rope is coiled on the packs, and the end of the lash rope brought up on top. The cincha of the second pack is laid down on one side of the first and parallel to it at 2 feet distance, but with the end of the lash rope on the opposite side. The packs, etc., are placed on it as described. The third pack is placed on the other side of the middle one, and so on until all are down in a line. After all cargoes are off, the aparejos are removed. Cargoes are also covered with pieces of canvas called **cargo covers.** Mantas may be used if there are spare ones.

19. **Marches.**—A draft mule is rested by a halt; a pack mule is not unless unloaded. Wagon trains should start early and make frequent halts. These should be of two classes, longer ones at regular time intervals, and shorter ones of a minute or two after every unusually hard pull. The length and interval of the longer halts will depend upon the time and distance to be made.

As a rule, if a mule has made one dead pull, he will not try to pull again on the same load in the same place. When it is evident that the team must stop, the driver should stop it before it is stalled; otherwise, in most cases, he can not get another pull out of the team. A very slight change of conditions will often encourage stalled mules to pull again. Cases have been reported in which reversing the near and off mules had the desired effect. A little visible assistance, as a few men on dragropes, has an excellent effect. Most mules on a hard pull will not go into the collar gradually as a horse does, but will throw themselves forward, and if the load does not move, will immediately fall back. It is difficult to get a steady lay-down pull out of a team of mules in which every animal is doing his best at the same moment. A team of two mules on a hard pull will often seesaw on the doubletrees without pulling as much as either could alone. It is better to have stop chains on the doubletrees, leaving only enough slack to prevent one mule from shirking.

It may be quicker, in case of great obstacles, to unload wagons and take them to pieces and carry over, than to attempt to haul over. A portage may also be made when otherwise the train could not advance at all.

A pack train should be allowed to make its march without halts except for water, if it can be done. They may start later or get in earlier, according to circumstances. If the column is of great length, no relief can be given them in this way, and they must halt with the rest.

When going into bivouac or camp, the company and headquarters ration and baggage wagons are conducted at once to the sites of their respective kitchens. If a bivouac, they remain there all night, unless in the presence of the enemy; if a camp, they are unloaded, and join the rest of the train in park.

The train is parked in line, preferably to leeward of the camp, and on ground which does not drain toward it. The picket line will be stretched parallel to the wagon line and preferably in front of it, though always on dry, gently sloping ground, if it can be found. The best site is along a ridge with the ground sloping both ways from the line. The mules stand on both sides, and there should be 3 yards of line for each 4 mules. If the 4-mule wagons are 3 yards apart in park and the 6-mule wagons 4½ yards apart, tongue to tongue, each team at the picket line may stand in front of its own wagon, which is a very convenient arrangement.

Picket lines are of two kinds, **ground** and **high.** A **ground line** is stretched on the ground, attached at its ends and at intervals of about 30 yards to stakes or some other form of holdfast. A 1 inch diameter rope of sufficient length should be carried for the purpose, but, if necessary, a ground line may be made up of picket or lash ropes. A **high line** is stretched on trees or stakes set in the ground. If stakes are used, they should be at least 8 feet long, set 3 feet in the ground. At 4½ feet from the ground, holes should be bored large enough to take the line. From each end post the line should run obliquely to the ground and be attached to a holdfast. A high line for temporary use may be obtained by running every fifth wagon to the front and stretching the line across them. The end wagons should be loaded ones, and all must have the brakes set. Picket lines will be stretched with tackle if any is at hand; otherwise, by the following method: Attach the rope at one end and lead it through all the supports or fastenings; about 15 feet from the other end make a bowline in the rope, pass the end around or through the end fastening and back through the bowline. By hauling on the end of the rope the necessary strain may be set on the line, the bowline acting as a single block. The end stakes of a high line should incline outward slightly.

The **picket line should be ditched** if it is to be used for some time, and if rain threatens it should be ditched even for a bivouac. The only exception is when the line is on a ridge and the ground slopes from it in both directions. Open a ditch on the high side about 3 yards from the line. If the ground slopes along the line, the ditch will be parallel to it, and will have an outlet at the lower end; otherwise, the ditch must be farther uphill at the middle, and will have an outlet at each end. This drainage should be kept in mind in locating the line.

20. **Stable duties.**—The prime requisites in stabling mules are free circulation of air without drafts, equable temperature, dryness, and cleanliness. Grain is fed at reveille by the stable orderlies. When the animals have finished eating, those to be used are harnessed and hitched up. The rest are turned into the corral or tied at the picket line. The stable police then fork all clean and dry bedding to the head of the stall and work the rest of the manure into piles ready for loading. The manure wagon is driven down the aisle and loaded. The hay is then distributed to the mangers and the additional bedding is procured and spread. The aisle may then be washed with hose and brooms if the air is dry; if damp, do not wash, but sweep up with stable brooms. The evening feed is put in the mangers **at afternoon stables.**

Mules of the same team should stand together, and their harness should be hung on racks in rear of their stalls. It is much better to have harness covers to keep off dust.

Grooming is quite as important to the mule as to the horse, but he does not get so much of it, and in the nature of things he can not. He should be groomed every day if it can possibly be done. When coming in from a long muddy march the wet mud should be wiped off with a wisp of straw before it dries and hardens. If the animal will not stand, tie up a hind foot as described in *shoeing*. Always tie up the foot on the side opposite to that which is to be groomed.

21. **Shipping mules by rail.**—The cars furnished may be either:

The **palace stock car,** length 36 to 40 feet, capacity 16 to 20 head; each animal in a separate stall, with a compartment for attendants, or

The **improved stock car,** length 36 feet, capacity 20 to 24 head, with facilities for feeding and watering in car, or

The **ordinary stock car,** length 30 to 34 feet, capacity 16 to 20 head, with no appliances of any kind.

Before loading, examine the car carefully to see that the floors are not rotten or broken; that the sides are secure, and that there are no projecting nails or splinters on the inside. The car should be cleaned and the floor covered with sand or sawdust. Hay or straw should never be allowed in a stock car on account of the danger from fire. The man in charge should be provided with a lantern, bucket, and hatchet. The latter is to be used to cut away part of a board in case an animal gets his hoof through the side of the car.

Except in very hot weather, pack the animals snugly in the car, as they will ride better than if loosely packed. If an animal falls down in the car it will be almost impossible for it to get up without assistance. The attendant should enter the car at the end and crawl along the side nearest the animal's head until he is reached. Take him by the halter and raise his head. With this assistance he will probably get us. For loading, use the railroad platform or the loading ramp found at railroad stations, or make a ramp well supported, with strong sides, and with cleats on the floor to prevent slipping. Lanyards should be attached to each side of the floor near the middle and made fast to truss rods or door fittings of the car to prevent the ramp from sliding off the doorsill.

If lumber is not at hand a ramp may be made of poles and brush, supported on trestles and floored like a bridge. (See Bridges.) As a last resort throw up a ramp of earth, reaching as near as possible to the side of the car, and bridge the gap with the car door.

For loading with improvised facilities, always try to get the car into a shallow cut.

Lead the animals up the ramp and into the car and take off the halter straps but not the halters. If the mules are shy of the ramp a little hay thrown on it will make them less timid. Very obstinate cases can be handled by passing a rope around the haunches and having a few men pull on each end. The first animal is led to one end of the car and the second to the other end, leaving the middle for the last ones loaded. The animals face opposite sides of the car alternately. Each one led in must be held until the next one is in place. Load quietly and avoid exciting the animals either by haste or by unnecessary delay. It may occasionally be necessary to blindfold an animal before he can be led in. Animals in transit should be fed and watered once a day at least, or twice if opportunity offers. If closely packed in ordinary cars they should be unloaded and exercised once in 48 hours and given 6 hours' rest.

22. **Shipping animals by sea.**—Ships must be especially fitted up and equipped for this service. Free ventilation and cleanliness are of the utmost importance. Air ports should be large and numerous and wind sails must be set up in every hatch to each deck. If there are dead spaces, special air shafts must be built to supply them. If there is machinery on board, forced ventilation should be employed. Animals do best on deck, except in very heavy weather, and should never be put below the water line. Stalls are built in double rows lengthwise of the ship facing each other, with a 4-foot aisle between. There should be a passageway athwartships at each end of each compartment, and if the vessel is wide enough the outside rows of stalls should be 3 feet from the sides of the ship

Stanchions 6 by 6 inches are set up 30 inches c. to c. lengthwise and 6 feet 6 inches c. to c. athwartships between the posts of the same stall. The stanchions are well secured at top and lightly to the deck. Before setting up, the stanchions are mortised for the side boards as shown in figures 20 and 21. The stanchions should be further stayed near the tops by ties in both directions, fastened to or firmly butting against the framework of the vessel. The ties should run straight, disregarding the curve and sheer of decks. A false floor of 2-inch plank 8 to 12 inches wide is spiked or bolted to the deck, the planks running lengthwise of the stalls, with $\frac{3}{4}$-inch space between them. If the ship is to be used for this purpose for a considerable time, the floor should be double, with tar paper between the courses. The floor is cut closely around the feet of the stanchions. Hardwood cleats are placed across the stall and fastened to the false floor with screws. In spiking down the false floor the nails should be so driven that their heads will be covered by these cleats. Larger cleats are laid lengthwise from foot to rear posts. The stall partitions are of 2-inch plank, smoothly planed (fig. 22), inserted in the mortises in the stanchions, and the rear ends are closed by haunch pieces. These are shaped as shown in section in figure 23 and are fastened by lag screws to a plank bolted to the rear posts. The haunch piece is adjustable in height (fig. 24) and should be placed so that its bottom edge will catch the mule 2 inches above the hock. The front is best closed by a heavy canvas band 8 inches wide, with reenforced edges, a spreading stick at each end and a grommet in each corner for lashing it to the front posts. A light strap over the neck will keep this band in place like a breast collar and the lashings may be left slack enough to permit the mule to sway and ride easier. Projecting nails must be avoided, edges and corners smoothed and rounded, knot holes trimmed out and splinters removed, and all parts which the mule can reach with his teeth should be sheathed with metal or wrapped with wire.

For deck stalls the posts are capped to form supports for a roof of 2-inch stuff, which should be covered with tar paper. The stalls must also be strongly cross-braced. This is best done by inserting diagonals between the posts of every fifth or sixth partition. The entire structure must be thoroughly strapped or tied down to the deck.

Under no circumstances should any stock be loaded until the ship is ready to sail, completely equipped, supplied, and manned.

Watering is easily done by buckets filled from a hose, the nozzle of which is carried along the aisle. The nozzle should have a cock to enable the flow to be controlled at the end. The supply should not be less than 10 gallons per mule per day. If condensers are used, there should be several days' supply in fresh-water tanks to provide against a breakdown of the machinery or the use of water not thoroughly cooled.

Feeding is best done on the false floor in front of the stalls. Cleats may be nailed down to form shallow boxes to hold the grain in place. In heavy weather it may be better to use nosebags. Grain should be fed early in the morning. None should be given the first day out. The second day a half ration should be fed and increased by small quantities if found necessary to keep the animals in condition. Bran mashes with salt should be fed once a week. After feeding the deck should be thoroughly cleaned and such dis-
[illegible] its as are to be used should be applied. Then the hay should

[illegible] etter to leave one vacant stall in each tier. Remove the side
[illegible] d shift the next animal into the vacant stall. Clean his
[illegible] ughly and shift the second animal into it, and so on.
[illegible] **ng** and **unloading** the animals should be led up and
[illegible] and gangways if possible. If they are to be transferred
[illegible] ighters, or dropped into the water to swim ashore, a
[illegible] g stall must be used. After landing, animals should

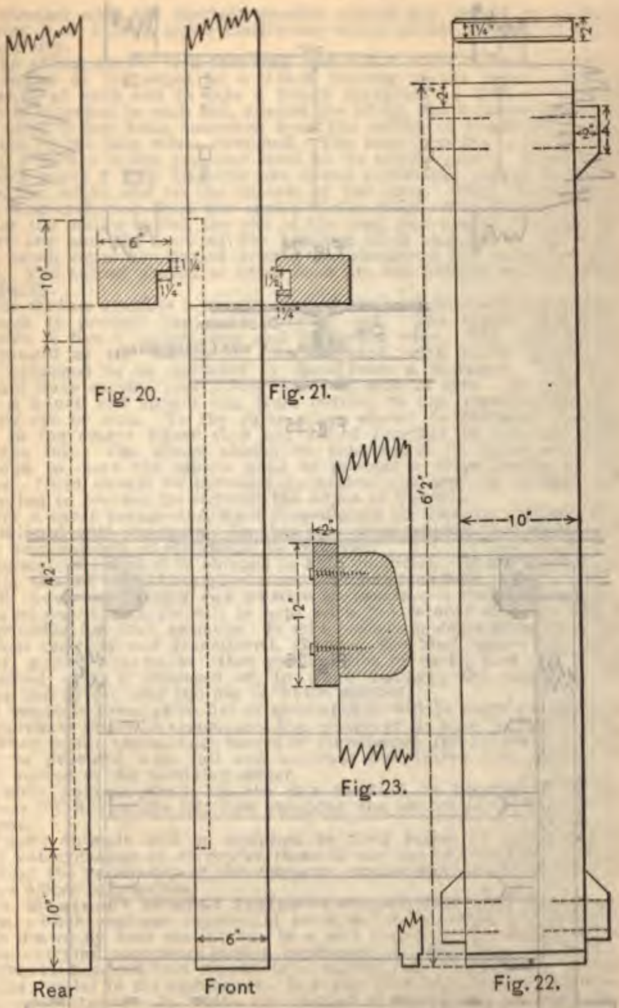


Fig. 20.

Fig. 21.

Fig. 23.

Fig. 22.

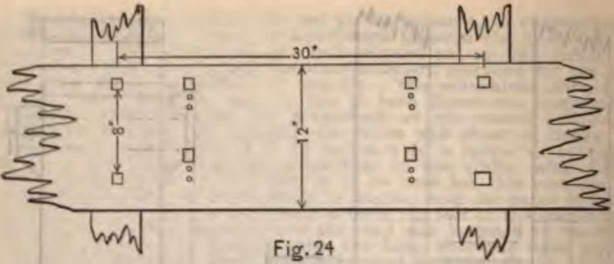


Fig. 24

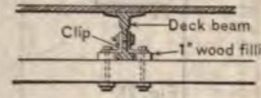


Fig. 25

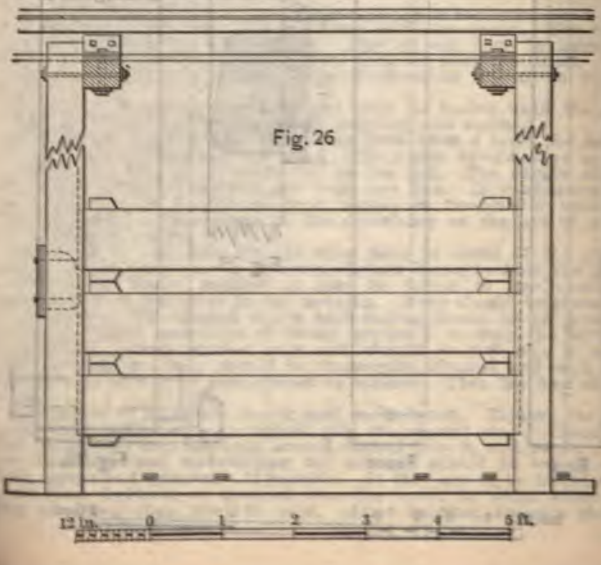


Fig. 26

be corraled with the shortest possible march and should be allowed to rest 3 or 4 days under conditions which permit gradual increase of activity.

The **sling** should be 5 feet long and 2 feet wide, of heavy canvas, reinforced at the edges by a 2-inch binding of the same. A hem is made at each end to take a 2-inch spreader. A loop of 1½-inch rope is attached to each end, around the sticks, one 9 inches long and the other 3 feet long, measured from the middle of the sticks to the middle of the loop when stretched. The long loop has a heavy iron ring, 3 inches inside diameter fixed at its middle point. Breast and haunch ropes ¾ inch diameter are sewed across the canvas 3 inches from the sticks and on the outside of the sling. They should be 9 feet long each way from the center of the sling. The sling is placed under the mule's barrel, the end of the long loop passed through the short one and the hook of the hoisting block engaged in the ring. The small ropes are passed around the shoulders and haunches and tied. The animal should be lifted from his feet quickly and set down gradually.

The **flying stall** is a stoutly framed box open at the top and high enough to prevent the mule jumping out. The inside should be smooth, 6 feet 6 inches long and 30 inches wide. The ends should be hinged at the bottom to open outward, with heavy latches at top arranged to be operated by lines from a distance. The floor should have several cleats running from side to side. At each corner a ½-inch rod should run from bottom to top, terminating in a heavy eye or ring. To the rings slings should be fastened converging to the center where they are joined together to take the hook of the fall. The slings should be kept apart by spreaders high enough to clear the mule's head to prevent a cross strain on the sides. Guys should be provided to control the stall in raising and lowering to prevent its striking the edges of hatches.

For a short voyage and work immediately on landing, animals may be shipped with shoes on. In this case shoes should be recently set. For long voyages, shoes should be removed.

Animals should not be shipped in high condition. If not worked up to the time of embarking, give exercise and reduce feed.

23. **Accountability for public animals.**—A file of descriptive lists of public animals will be kept with the records of every officer responsible for such animals. It will contain a description of every animal received and transferred, showing the kind, name, age, size, color, marks, brands, or other peculiarities of each; how and when acquired, and, if disposed of, in what manner; the name of his rider and driver, and the use to which applied.

A complete descriptive list of each animal will be made at the time of purchase and will accompany him wherever he may be transferred.

When public animals are issued or transferred, the person in charge will be provided with full and accurate descriptive lists, which he will deliver to the receiving officer.

Public animals shall, on the day received be branded with the letters "U S" on the left fore shoulder, the letters to be 2 inches in height.

Public animals will be assigned to their riders or drivers, who will not exchange or surrender them to the use of any other person without the permission of the company commander, quartermaster, or other officer responsible.

24. **Engineer combat trains—Composition and distribution.**—Each engineer regimental headquarters has two tool wagons, each drawn by four mules; one is a tool wagon of the escort-wagon type, carrying map-reproduction equipment and supplies. The other regimental-headquarters wagon is a spring tool wagon of a special design similar to the ambulance. It is provided with lockers, drawers, and compartments, in which are carried the drafting, photographic, reconnaissance, surveying, and miscellaneous equipment and supplies.

Each battalion headquarters of an engineer regiment has one tool

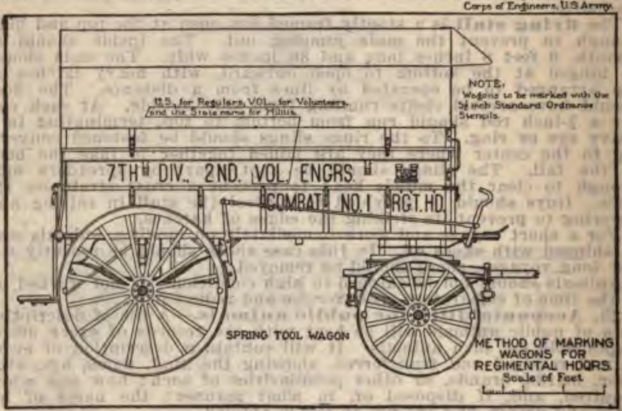

Corps of Engineers, U.S. Army.
NOTE.
Wagons to be marked with the 5/8 inch Standard Ordnance Stencils.
U.S., for Regulars, VOL., for Volunteers, and the State name for Militia.
7TH DIV., 2ND. VOL. ENGRS.
COMBAT NO. 1 RGT. HD.
SPRING TOOL WAGON
METHOD OF MARKING WAGONS FOR REGIMENTAL HDQRS.
Scale of Feet

Fig. 27.

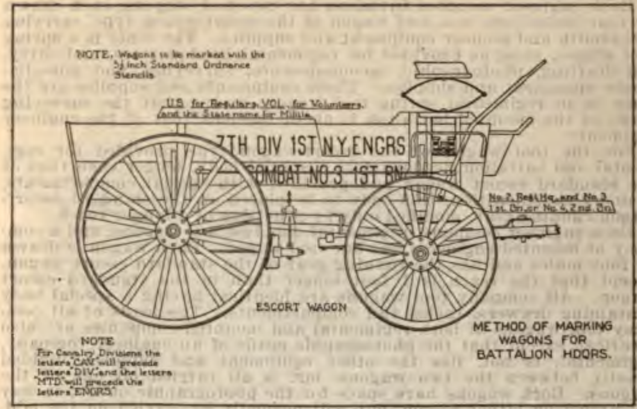

NOTE, Wagons to be marked with the 5½ inch Standard Ordnance Stencils
U.S. for Regulars, VOL. for Volunteers, and the State name for Militia.
7TH DIV 1ST N.Y. ENGRS
COMBAT NO 3 1ST BN
No. 2, Regt Hq. and No. 3 1st. Bn. or No. 4, 2nd. Bn.
ESCORT WAGON
NOTE
For Cavalry Divisions the letters "CAV" will precede letters "DIV." and the letters "MTD" will precede the letters "ENGRS."
METHOD OF MARKING WAGONS FOR BATTALION HDQRS.

Fig. 28

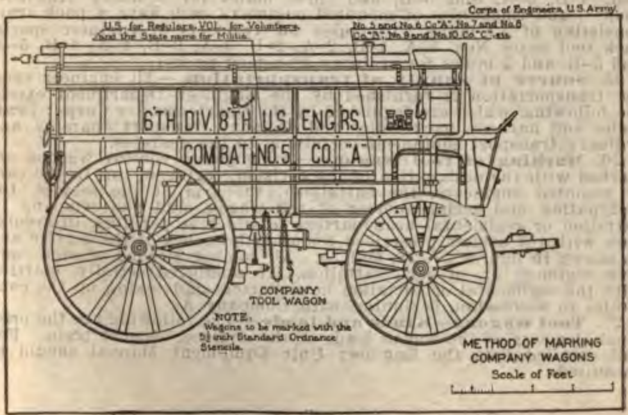

Corps of Engineers, U.S. Army.
U.S. for Regulars, VOL. for Volunteers, And the State name for Militia.
No. 5 and No. 6 Co "A", No. 7 and No. 8 Co "B", No. 9 and No. 10 Co "C", etc.
6TH DIV. 8TH U.S. ENGRS.
COMBAT NO. 5 CO. "A"
COMPANY TOOL WAGON
NOTE.
Wagons to be marked with the 5½ inch Standard Ordnance Stencils.
METHOD OF MARKING COMPANY WAGONS
Scale of Feet

Fig. 29

wagon of the escort-wagon type, carrying blacksmith and pioneer equipment and supplies, with sufficient space remaining for the headquarters baggage.

Each engineer mounted battalion has two tool wagons, each drawn by four mules; one is a tool wagon of the escort-wagon type, carrying blacksmith and pioneer equipment and supplies. The other is a spring tool wagon, same as provided for regimental headquarters, and carrying drafting, photographic, reconnaissance, surveying, and miscellaneous equipment and supplies. These equipments and supplies are the same as in regimental spring tool wagon, except that the surveying outfit of the mounted battalion is about one-half that of the engineer regiment.

For the tool wagon of the escort-wagon type provided for regimental and battalion headquarters a special body, longer than that of the standard escort wagon and provided with special compartments, is under consideration, this body to be placed on the standard escort-wagon running gear, modified only by provision of a longer reach.

Each engineer company, regimental, has two tool wagons, and a company of mounted engineers has one tool wagon. Each wagon is drawn by four mules and has the running gear of the standard escort wagon, except that the reach is 1 foot longer than in the standard escort wagon. All company tool wagons are identical having a special body containing drawers, racks, and compartments. The loads of all company tool wagons of both regimental and mounted companies are also identical, except that the photographic outfit of an engineer company, regimental, is not, like the other equipment and supplies, divided equally between the two wagons, but is all carried on one of the wagons. Both wagons have space for the photographic outfit; it may be carried on either wagon, but will normally be carried on the odd-numbered wagon.

In addition to their tool wagons, engineer companies, regimental, each have a pack train consisting of eight mules (five mules for engineer special pack tool boxes Nos. 1–A, 1–B, 2–A, 2–B, 3–A, 3–B, 4–A, 4–B, 5–A, and 5–B, and three mules for ordinary transport packs), and companies of mounted engineers each have a pack train consisting of 12 mules (10 mules for two sets of engineer special pack tool boxes Nos. 1–A, 1–B, 2–A, 2–B, 3–A, 3–B, 4–A, 4–B, 5–A, and 5–B, and 2 mules for ordinary transport packs).

25. **Source of supply of transportation.**—All engineer combat transportation is furnished by the Engineer Department except the following, which are furnished by the Quartermaster Corps: Draft mules and harness, pack mules and ordinary transport aparejos, and ordinary transport equipment pertaining to the aparejos.

26. **Marking of tool wagons.**—All engineer combat wagons are marked with the designation of the division, regiment (or, in the case of mounted engineers, the battalion), the arm of the service, the designation and serial number of the wagon, and the company or battalion or regimental headquarters to which it pertains, in accordance with the system prescribed for other branches of the service and as shown in figures 27, 28, and 29. All combat wagons of each engineer regiment or, of each battalion, are numbered serially, starting with the regimental or battalion headquarters and taking up the companies in succession, beginning with Company A.

27. **Tool wagons—Kinds and loads.**—The following are the principal elements of the wagon loads of the engineer combat train. For full detailed lists the Engineer Unit Equipment Manual should be consulted.

(a) LOADINGS OF HEADQUARTERS TOOL WAGONS, ESCORT-WAGON TYPE.

	Engineer regiment.		Mounted engineers, battalion headquarters.
	Regimental headquarters.	Battalion headquarters.	
Blacksmith equipment:			
Anvil, B. S., 100 pounds, with B. S. apron, coal bags, chisels, clinch cutter, clinching iron, countersink, flatter, 2 inches; fullers, T and B, $\frac{3}{8}$-inch; hammers (7); hardy; heading tools, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch; rivet headers, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch; punches, $\frac{3}{8}$ and $\frac{3}{4}$ inch; swedges, T and B, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch; and tongs		1	1
Brace, ratchet, and set of 13 drills (range of sizes) $\frac{8}{32}$ to $\frac{16}{32}$ by thirty-seconds, $\frac{9}{16}$ to $\frac{3}{4}$ by sixteenths		1	1
Files, assorted, 8 to 16 inches		10	10
Forge, portable, with rake and shovel		1	1
Hammer, sledge, 10 pounds		1	1
Handles, assorted		10	10
Oiler, $\frac{1}{2}$ pint		1	1
Pipe cutter, No. 2 (size, $\frac{1}{2}$ to 2 inches)		1	1
Rule, 2-foot folding		1	1
Shoeing outfit, including shoeing knives, toe knives, nippers, pinchers, rasp, and tongs		1	1
Stocks, dies and taps, No. 2, sets (size, $\frac{1}{2}$ to $1\frac{1}{4}$ inches by eighths)		1	1
Tire measure		1	1
Vises, B. S., 4-inch jaws		1	1
Wrench, monkey		1	1
Blacksmith supplies, sets, consisting of—			
Borax, 5 pounds; coal, blacksmith's, 4 bushels; nails, horseshoe, 25 pounds; nuts, assorted, 40 pounds (sizes, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch); oil, machine, 1 quart; steel, soft, bars, 156 feet (sizes, $\frac{1}{8}$ by 1 inch and 2 inches; $\frac{3}{8}$ by $1\frac{3}{4}$ inch and 2 inches; 1 by 2 inches; and $\frac{1}{2}$, $\frac{3}{4}$, and 1 inch round); steel, tool, 5 feet (size, $\frac{3}{4}$-inch octagon)		1	1
Map reproduction equipment:			
Buckets, galvanized iron (capacity, 14 quarts)	3		
Cans, galvanized iron, 5 gallons	2		
Cans, galvanized iron, 3 gallons	1		
Chests, zincographic (sets of 3) for prints 24 by 30 inches, with suitable bottles, bowls, brushes, glazed rollers, knives, needles, zinc plates (16), press (hand), roller grip, rollers (leather), snakestone, sponges, trays (20 by 24 inches), and whirler	1		
Frames, blue print, 24 by 30 inches, with tray (24 by 39 inches) and tin tubes (2)	1		
Instruments, drawing, lithographic, sets, with triangles and "T" square	1		
Lanterns, Dietz	2		
Screw drivers (3-inch blade)	1		

(a) LOADINGS OF HEADQUARTERS TOOL WAGONS, ESCORT-WAGON TYPE—Continued.

	Engineer regiment.		Mounted engineers, battalion headquarters.
	Regimental headquarters.	Battalion headquarters.	
Map reproduction equipment—Continued.			
Shears, 16-inch	1		
Stoves, oil, single burner	1		
Tents, hospital, with shield, complete	1		
Towels, bath	4		
Wrench, monkey, 12-inch	1		
Zincographic outfit supplies, sets, for cleaning zinc plates: Nitric acid, 5 pounds; flash, 12 cans; pumice, 5 pounds; caustic soda, 10 pounds. For photographic transfer: Brown print paper, 30-inch, 10 yards; chromic, 2 pounds; phosphoric, 2 pounds; and tannic, 1 pound; albumen, 2 pounds; ammonium bichromate, 1 pound; absorbent cotton, 3 pounds. For direct transfer process: Autographic paper, 17 by 20 inches, 2 gross; touche, 4 ounces; autographic ink, 6 ounces. For etching and retouching plate: Chromic, phosphoric, tannic acids; alum, powdered, 2 pounds; asphaltum, 1 pound; lavender oil, 1 ounce; olive oil, ½ pint; banana oil, 8 ounces; beeswax; dragon's blood, 1 pound; gum arabic, 25 pounds; etching ink, 1 pound; willow charcoal, 1 pound; etching slips; resin powder, 2 pounds; tallow, 4 ounces; turpentine, 3 gallons. For printing and drying: Book paper, 19 by 24 inches, 5 reams; blotting paper, 19 by 24 inches, 6 dozen; cheesecloth, white, 300 yards; hand-press ink, 3 pounds; turpentine. Miscellaneous: Coal oil, 10 gallons; thumb tacks, 2 dozen; varnish, 1 pint; lantern and oil-stove wicks. Blue-print outfit: Blue-print paper, 30-inch, 50 yards, 1 roll	1		
Pioneer outfit: Screw jacks		2	
Army wagon parts, extra (furnished by the Engineer Department):			
Blocks, brake	2	2	2
Bolts, assorted, sets, king, 1 by 18 inches (1); tire, ½ by 2¾ inches (1), ½ by 3 inches (5); wagon, ⅜ by 1½ inches (2), 7/16 by 1¾ inches (2), 7/16 by 2 inches (1), 7/16 by 2½ inches (2), ⅝ by 3 inches (2), ½ by 11 inches (1), ⅝ by 4 inches (4)	1	1	1
Links, open	3	3	3
Nuts, axle (1 R. H. and 1 L. H.)	2	2	2
Rivets, iron, 5/16 by 1½ inches (6), ¼ by 1½ inches (4)	10	10	10
Tongue, reach, doubletree, singletree (of each)	1	1	1

(a) LOADINGS OF HEADQUARTERS TOOL WAGONS, ESCORT-WAGON TYPE—Continued.

	Engineer regiment.		Mounted engineers, battalion headquarters.
	Regimental headquarters.	Battalion headquarters.	
Army-wagon accessories (furnished by the Quartermaster Corps):			
Currycomb, horse brush, whip, and bucket, G. I. (of each)	1	1	1
Grease, axle, pounds	4	4	4
Nose bags, halter with strap (of each)	4	4	4
Army-wagon harness parts, extra (furnished by the Quartermaster Corps):			
Buckles, ¾, ⅞, 1, and 2 inch (1 of each)	4	4	4
Clips, trace	2	2	2
Hames	2	2	2
Rings, ¾, 1, 1½, and 2 inch (1 of each)	4	4	4
Snaps, 1, 1¼, and 2 inch (1 of each)	3	3	3
Straps, hame	3	3	3
Army-wagon harness accessories and supplies (furnished by the Quartermaster Corps):			
Oil, neat's-foot, gallon	½	½	½
Shoes, mule, fitted with 8 nails each	16	16	16
Soap, harness, pounds	1	1	1
Sponge	1	1	1
Wire, stove, spool	1	1	1

(b) LOADINGS OF HEADQUARTERS TOOL WAGONS—SPRING.

Drafting equipment:			
Board, drawing, 31 by 42 inches, with trestle, with the following equipment: Office set drawing instruments; proportional dividers; steel eraser, erasing shield; map measure; protractor, 8-inch, G. S., in case; scale, 12-inch, engineer; scale, 12-inch, architect; slab, ink; slide rule, 16-inch; T square, 42-inch; triangle, 30°-60°, 10-inch; triangle, 45°, 8-inch sets	2	....	2
Lamps, acetylene	2	....	2
Pantograph	1	....	1
Tent, hospital, regulation, with shield, complete	1	....	1
Tubes, tin	4	....	4
Drafting supplies:			
Books, note (3); erasers, rubber (3); ink, drawing, bottles, black (2), blue (1), brown (1), carmine (1); ink, India, 1 stick; paper, blotting, 3¾ by 9½ inches, 1 dozen; cross-section, 20-inch, 5 yards; drawing, 30-inch, 30 yards; wrapping, 40 by 48 inches, sheets, 2 dozen; pens, crow-quill, dozen, with holder (1), mapping, dozen, with holder (1); pencils, drawing, H, 3H, and 5H (1 dozen each); pencil-pointing pad (1), scratch (2); thumb tacks, 3 dozen; tracing cloth, 30-inch, 24 yards set	2	....	

(b) LOADINGS OF HEADQUARTERS TOOL WAGONS—SPRING—Continued.

	Engineer regiment.		Mounted engineers, battalion headquarters.
	Regimental headquarters.	Battalion headquarters.	
And the following miscellaneous supplies:			
Pins, cones	1	....	1
Paste, library	1	....	1
Tape, adhesive, rolls	4	....	4
Twine, hemp, 2-ounce ball	2	....	2
Miscellaneous equipment:			
Manuals, Engineer Field	2	....	2
Padlocks, brass	5	....	5
Photographic equipment: Camera, 3A Graflex, with folding tripod (Crown No. 2)	1	....	1
And the following accessories: Agate trays (4); bath towels (4); canvas buckets (2); chamois skin; duplicating tanks, set; film tank; graduate, 8-ounce; photographer's manual; printing frames, 5 by 7 inches (2); rubber blankets (2); ruby lamp; shears, 8-inch; spotting brush; stirring rods (2); thermometer......set..	1	....	1
Photographic supplies:			
Developer, M. Q. and Pyro, tank, boxes of each	15	....	15
Films, 3A, 6-exposure	48	....	48
Hypo acid, 1-pound boxes	48	....	48
Paper, developing, 3A size......gross..	3	....	3
And the following: Absorbent cotton; alcohol, denatured, 1 pint; cheesecloth, white, 3 yards; film albums, 3A size (2); formaline, 1 pound; intensifier, 6 tubes; opaque, 1 tube; photo clips (24); photo notebooks (2); potassium bromide, tabloid, 6 tubes; pushpins (24); twine, [illegible] 1 ball; wicks for ruby lamp (6)......set.	1	....	1
Reconnaissance equipment:			
Cases, sketching outfit, each containing: Base tally; pencil packet; rectangular protractor; service clinometer; sketching board, with alidade and folding tripod; timing [illegible]	3		3
And the following additional equipment—			
Barometers, aneroid, with case	2		2
Clinometers, service, with case	4		4
Compasses, box (2), prismatic with case [illegible]	[illegible]		10
[illegible] with cases	[illegible]		2
[illegible]	[illegible]		4
[illegible]	[illegible]		1
[illegible]			
[illegible]	[illegible]		16
[illegible]	[illegible]		36
[illegible]	[illegible]		14
[illegible]	[illegible]		18
[illegible] sheets, gross			12

(b) LOADINGS OF HEADQUARTERS TOOL WAGONS—SPRING—Continued.

	Engineer regiment.		Mounted engineers, battalion headquarters.
	Regimental headquarters.	Battalion headquarters.	
Reconnaissance supplies—Continued.			
Pencils, drawing, H (42), blue (14), red (14), green (14)	84	....	84
Protectors, pencil-point	14	....	14
Tape, adhesive, rolls	6	....	6
Surveying equipment:			
Boards, stadia	6	....	2
Field glasses, with case	1	....	1
Levels, engineer's, and tripods	2	....	1
Plane tables, complete, and tripods	1	....	....
Repair kit for steel tapes	1	....	1
Rods, level, Philadelphia	4	....	2
Slide rule, 16-inch, with case	1	....	....
Stadia computer	3	....	1
Tapes, steel, 100-foot	2	....	1
Transits and tripods	2	....	1
Surveying supplies:			
Books, level	4	....	2
Books, transit	6	....	2
Cloth, signal, red and white, yards (of each)	30	....	15
Paper, plane table, sheets, dozens	2	....	....
Spring tool-wagon parts, extra (furnished by the Engineer Department):			
Bolts, one each except where shown—¼-inch carriage, 1½, 1¾, 2½, 2¾ inch; 3/16-inch carriage, 1½ inch (2), 2¼ inch; 5/16-inch carriage, 2, 2½, 3 inch (2); ⅜-inch carriage, 3½, 4. 5½, 6 inch; king, ¾ by 12 inches; machine, 7/16 by 2¼ inches; ¼-inch tire, 2 inch (2), 2½ inch (4); 5/16-inch tire, 1¾, 2½ inch; ⅜-inch tire, 4½, 5½, 6 inch ... set	1	....	1
Brake block	1	....	1
Links, open	3	....	3
Nuts, axle (1 each R. H. and L. H.)	2	....	2
Rivets, iron, ¼ by 1¼ inches	2	....	2
Rivets iron, ¼ by 2½ inches	3	....	3
Screws, wood, flathead, No. 12, 1½ inch	2	....	2
Screws, rivet head, No. 9, 1¼ inch	3	....	3
Singletree	1	....	1
Tongue	1	....	1
Spring tool-wagon accessories (furnished by the Quartermaster Corps):			
Bucket, G. I., currycomb, horse brush, monkey wrench, and whip (of each)	1	....	1
Grease, axle, pounds	1	....	1
Halter, with strap, and nose bags	4	....	4
Harness parts, extra (furnished by the Quartermaster Corps):			
Buckles, ¾, ⅞, 1, and 1½ inch	4	....	4
Hames	2	....	2
Hame straps	3	....	3

(b) LOADINGS OF HEADQUARTERS TOOL WAGONS—SPRING—Continued.

	Engineer regiment.		Mounted engineers, battalion headquarters.
	Regimental headquarters.	Battalion headquarters.	
Harness parts, extra (furnished by the Quartermaster Corps)—Continued.			
Rings, ¾, 1, 1½, and 2 inch	4	....	4
Snaps, 1, 1¼, and 1½ inch	3	....	3
Harness accessories (furnished by the Quartermaster Corps):			
Oil, neat's-foot, gallons	½	....	½
Soap, harness, pounds	1	....	1
Sponge	1	....	1
Wire, stove, spool	1	....	1
Additional supplies (furnished by the Quartermaster Corps): Shoes, mule, fitted, with 8 nails each	16	....	16

(c) LOADINGS OF COMPANY TOOL WAGONS.

	Engineer company, regimental (one-half of quantities given below carried on each wagon).	Company of mounted engineers (one wagon only).
Carpenter equipment: Chest, carpenter's, containing augers, ship, handled (3); scratch awl; ax, handled, 32-inch (with extra handle); ratchet brace, and bits (2 auger, 1 expansion, 2 screw-driver); chisels, framing, handled (3), (one extra handle); cold chisel; wing dividers; draw knife; files, saw, taper (3); hammer, claw, (with extra handle); ratchets (5); 24-inch carpenter's level; mallet; oiler, ½-pint; oilstone; jack-plane; pliers; plumb bob; rules, 2-foot (4); saws, hand [rip (1), crosscut (2), compass (1)]; saw set; screw driver; squares, steel, carpenter's (1), try (1); tape, metallic, 50-foot; T bevel, and wrenches, monkey, 12-inch ....sets..	2	1
Carpenter's supplies:		
Chalk, carpenter's, pound	½	¼
Chalk lines, 40-foot	4	2
Pencils, carpenter's, dozen	1	½

(c) LOADINGS OF COMPANY TOOL WAGONS—Continued.

	Engineer company, regimental (one-half of quantities given below carried on each wagon).	Company of mounted engineers (one wagon only).
Demolition equipment:		
Augers, earth, handled, and ship, handled, 1¾-inch; bars, pinch, large, and wood, tamping; cold chisel; single bit drills, long and short; miner's spoon, long (one of each) .... set	2	1
Box, cap	2	1
Box, match	2	1
Circuit detectors	2	1
Crimpers	2	1
Hammers, sledge, 8-pound	4	2
Magneto exploders	2	2
Pick mattocks, E. D. pattern, "intrenching," handled	4	4
Shovels, E. D. pattern, "intrenching"	8	1
Spoons, miner's, long	2	0
Wire, firing, double-lead No. 14, on reel, feet	2,000	1,000
Demolition supplies:		
Caps, detonating	100	50
Explosives, pounds	200	100
Fuse, Bickford, feet	200	100
Fuse, instantaneous, feet	200	100
Fuses, electric	200	100
Matches, safety, boxes, dozen	1	½
Tape, insulating, rolls	2	1
Twine, hemp, 2-ounce balls	2	1
Drafting equipment:		
Boards, drawing, 23 by 31 inches (with trestles)	2	1
And the following equipment: Field drawing instruments (set); steel eraser; erasing shield; map measure; protractors, G. S., semicircular, 6-inch; scales, 12-inch; architect's (1) and engineer's (1); triangles, 30°-60° and 45°, and T squares, 24-inch .... set	2	1
Lamp, acetylene	2	1
Tubes, tin	6	3
Drafting supplies:		
Books, note	6	3
Carbide, in 10-pound cans, pounds	40	20
Cloth, tracing, 30-inch, roll, yards	48	24
Erasers, rubber, pencil (2), ink (1)	6	3
Ink, drawing, black (2), blue (1), carmine (1), bottles	8	4
Ink, india, stick	2	1
Pencil-pointing pad, 1¼ by 4 inches; scratch pad, 6 by 9 inches (2); blotting paper, 3¾ by 9½ inches, dozen (1); pins; adhesive tape (2 rolls) and twine (2-ounce ball) .... set	2	1
Drawing paper, 22 by 30 inches, sheets	288	144
Pencils, H and 3H (of each)	12	
Pens, crow-quill and mapping, with holder (of each)	24	
Thumb tacks	24	

(c) LOADINGS OF COMPANY TOOL WAGONS—Continued.

	Engineer company, regimental (one-half of quantities given below carried on each wagon).	Company of mounted engineers (one wagon only).
Hectograph equipment:		
Hectographs, clay, 20 by 24 inches	2	1
Levelers, hectograph	2	1
Sponges	2	1
Hectograph supplies:		
Ink, green (1), red (1), violet (2), bottles	8	4
Paper, book, 19 by 24 inches, quires	10	5
Miscellaneous equipment:		
Bags for nails, two 50-pound, one 100-pound	6	3
Buckets, galvanized-iron	6	3
Cans, galvanized-iron, 5-gallon	2	1
Carborundum wheels	2	1
Handles, ship-auger (1), sledge (1), hatchet (3), pick-mattock (6)	22	11
Lanterns, dark (3), Dietz (6)	18	9
Manuals, Engineer Field (12), Ponton (1)	26	13
Marlinspikes	2	1
Padlocks, brass	12	6
Stamps, steel, sets	2	1
Stencils, sets	2	1
Miscellaneous supplies:		
Canvas, 10-ounce, width 36 inches, yards	20	10
Grease, axle, pounds	10	5
Marline, pounds	36	18
Nails, 60-penny (100 pounds), 30-penny (50 pounds), 16-penny (50 pounds)	400	200
Oil, signal, gallons	10	5
Oil, machine, quarts	2	1
Staples, pounds	20	10
Screws, assorted, gross	6	3
Wicks, extra, dark lantern (6), Dietz (12)	36	18
Wire, B. & S. No. 16, pounds	50	25
Photographic equipment:		
Camera, 3A kodak	1	....
Tripod, metal, folding	1	....
And the following accessories: Rubber blankets (2); canvas buckets (2); bulb, rubber; prnting frames, 5 by 7 inches (2); graduate, 8 ounces; ruby lamp; Photographer's Manual; stirring rods (2); shears, 8 inches; film tank, 3½-inch; thermometer; towels, bath (4); and agate trays (4); set	1	....
Photographic supplies:		
Albums for 3A films, size 3¼ by 5½ inches	1	....
Books, photo note	1	....
Developer, M. Q. and Pyro, 8 boxes each, boxes	16	16
Films, 3A size, 6 exposures, size 3¼ by 5½ inches	24	24

(c) LOADINGS OF COMPANY TOOL WAGONS—Continued.

	Engineer company, regimental (one-half of quantities given below carried on each wagon).	Company of mounted engineers (one wagon only).
Photographic supplies—Continued.		
Hypo acid, in ¼-pound boxes, boxes	24	24
Paper, 3A developing, size 3¼ by 5½ inches (1 gross), printing out (1 gross), gross	2	....
And the following articles: Potassium bicarbonate, 1 pound; twine ball (2 ounces); cheesecloth, white, 3 yards; photo clips (12); formalin, 1 pound; intensifier, tube (1); pushpins (12); potassium bromide tabloid tube (1); reducer tube (1); and wicks, ruby lamp (6) ... set	1	1
Pioneer equipment:		
Adzes, handled, 32-inch	4	2
Axes, handled, 36-inch	26	13
Bars, pinch, large	2	1
Blocks, 8-inch, double; 8-inch, single; 8-inch, snatch; and 8-inch, triple	8	4
Bolts, clippers	6	3
Climbers, lineman's, set	2	1
Comealongs	4	2
Files, crosscut saw	6	3
Hammers, sledge, handled, 8-pound	4	2
Handles, extra, adz, 32-inch; ax, 36-inch, pick, railroad, 36-inch; saw, crosscut, 1-man; and saw, crosscut, 2-man	14	7
Hatchets	6	3
Knives, Gabion	18	9
Machetes, with sheaths	36	18
Mauls, wood	4	2
Peevies, handled	4	2
Picks, railroad, handled	6	3
Pick mattocks:		
E. D. pattern, "intrenching," handled	30	15
Large, handled	6	3
Pliers, side-cutting	18	9
Points, pike and hook	4	2
Posthole diggers	2	1
Rope, manila, 1-inch diameter, feet	500	250
Saw, crosscut, 1-man	2	1
Saw, crosscut, 2-man	4	2
Saw, hack (with 6 blades)	2	1
Saw tools	2	1
Shovels, E. D. pattern, "intrenching"	60	30
Shovels, long-handled	12	6
Tapes, metallic, 50-foot	4	2
Wedges, steel, 5-pound	4	2
Wrenches, monkey, 18-inch	2	1
Wrenches, Stillson, 18-inch	2	[illegible]

(c) LOADINGS OF COMPANY TOOL WAGONS—Continued.

	Engineer company, regimental (one-half of quantities given below carried on each wagon).	Company of mounted engineers (one wagon only).
Pioneer supplies:		
Bolts, drift, ¾-inch (40), ½-inch (40)	160	80
Lashings, manila, ¾-inch diameter, 50-foot (12), ½-inch diameter, 18-foot (25)	74	37
Sandbags, with binders	500	250
Tape, tracing, feet	3,000	1,500
Reconnaissance equipment:		
Chests, sketching outfit, each containing sketching board, with alidade, and folding tripod; service clinometer; timing pad holder; pencil pocket; rectangular protractor and pace tally	6	3
The following additional equipment—		
Barometer, aneroid, with cases	4	2
Clinometer, service, with cases	8	4
Compasses, box (2), prismatic, with cases (2), watch (6)	20	10
Field glasses, with cases	2	1
Odometers, with cases	2	1
Pace tallies	8	4
Protractors, rectangular	2	1
Sextants, pocket	2	1
Reconnaissance supplies:		
Books, note, field	32	16
Celluloid sheets	72	36
Erasers, rubber, pencil	28	14
Pads, timing	36	81½
Paper, sketching, sheets, gross	3	4
Pencils, blue (14), drawing, H (42), green (14), red (14)	168	18
Protectors, pencil-point	28	14
Tape, adhesive, rolls	12	6
Company tool wagon parts, extra (furnished by the Engineer Department):		
Bolts, king, 1 by 18 inches (1); tire, ¼ by 2¾ inches (1), and ¼ by 3 inches (5); square head, ⅜ by 2¼ inches (2); carriage, ⅜ and ½ by 4 inches (2), and ¼ by 2 and 3½ inches (4); carriage, $\frac{5}{16}$ by 3¼ inches (2) .....set	2	1
Links, open	6	3
Nuts, axle (one R. H. and one L. H.)	4	2
Reach, tongue, singletree, extra (of each)	2	1
Rivets, iron, $\frac{5}{16}$ by 2¾ inches (6) and ¼ by 2¾ inches (4)	20	10
Wrenches, axle	2	1
Company tool wagon accessories (furnished by the Quartermaster Corps):		
Nose bags, halters, and straps (of each)	8	4
Currycomb and horse brush (of each)	2	1
Grease, axle, pounds	8	4
Whips	2	1

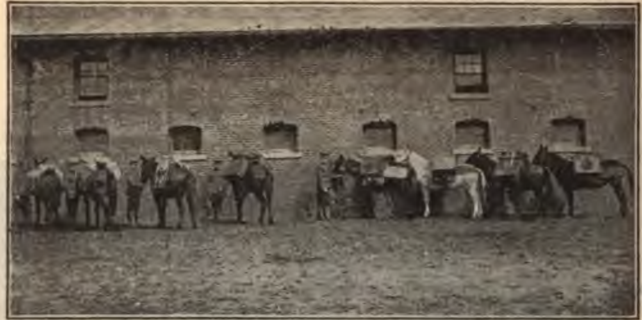


Fig. 30.—Company packs

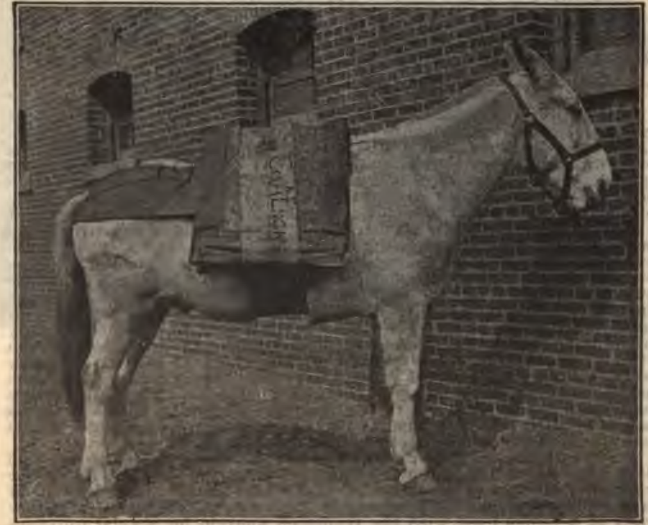


Fig. 31.—Aporejo

(c) LOADINGS OF COMPANY TOOL WAGONS—Continued.

	Engineer company, regimental (one-half of quantities given below carried on each wagon).	Company of mounted engineers (one wagon only).
Harness parts, extra (furnished by the Quartermaster Corps):		
Buckles, ¾, ⅞, 1, and 2 inch	8	4
Clips, trace	4	2
Hames	4	2
Rings, ¾, 1, 1½, and 2 inch	8	4
Snaps, 1, 1¼, and 2 inch	6	3
Straps, hame	6	3
Harness accessories (furnished by the Quartermaster Corps):		
Oil, neat's-foot, gallons	1	½
Soap, harness, pounds	2	1
Sponges	2	1
Wire, stove, spool	2	1
Additional supplies (furnished by the Quartermaster Corps):		
Mule shoes, fitted, and 10 nails	32	16

28. **Company packs.**—Means of carrying (fig. 30). The ordinary transport packs carry mantas (or pack covers), blinds, lair ropes, sling ropes, lash ropes (all furnished by the Quartermaster Corps), forage, and miscellaneous supplies not part of the prescribed pioneer equipment. The special pack boxes are carried on the ordinary transport aparejo, on which they are slung by a special small leather saddle 10 by 24 inches, which fits along the ridge of the aparejo and is lashed thereto with a leather thong. This saddle has two hooks on each side, from which are hung the pack boxes. The pack boxes are further secured on the aparejo by means of a cincha 22 inches long, fastened to the lower part of the boxes and passing under the mule. Except in the cases of pack boxes Nos. 4–A and 4–B, the cincha ring is attached to the pack boxes by means of a spider. In the case of boxes 4–A and 4–B the lashing ring is attached directly to the box, thus bringing the end of the cincha to the same position with all packs. Figure 30 shows all the types of pioneer company packs on the animals. Figure 31 shows the ordinary transport aparejo held on the animal by the aparejo cincha. Figure 32 shows the special saddle attached to the aparejo. Figure 33 shows the pack complete, with spider straps, latigo, or cincha strap, and box cincha ready to be hung on the hooks of the special saddle.

29. **Securing ordinary transport packs.**—(*a*) The diamond h (fig. 34). The following description of the diamond hitch for ary transport packs is taken, with slight change, from Manual of Transportation, Quartermaster Department, 1910, Daly. Other of lashings used with the transport aparejo for special purposes so be found in that manual.

formation of the diamond hitch and tightening of the load is shed by two packers—one, termed the "near" packer, who

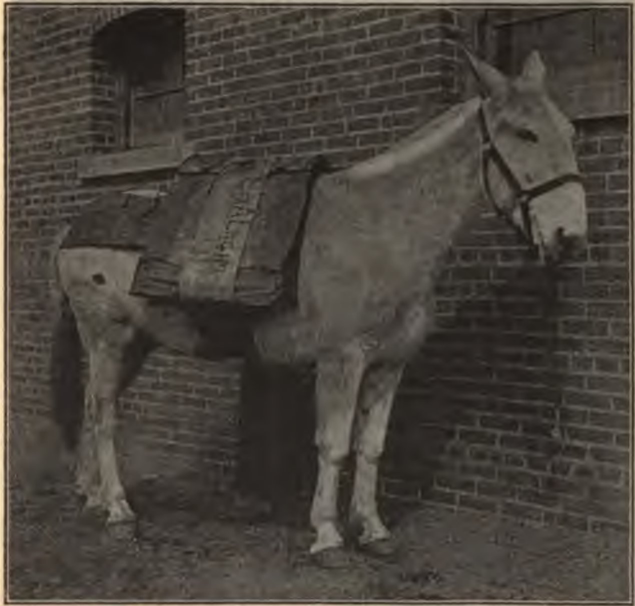


Fig. 32.—Special saddle

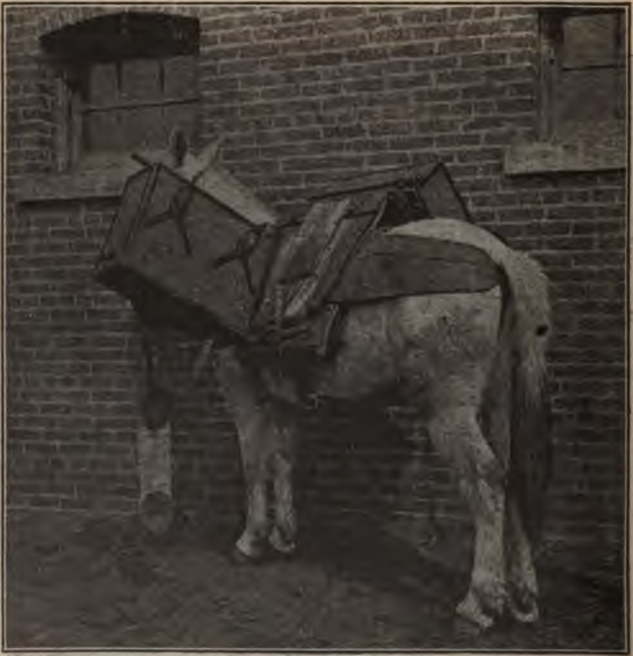


Fig. 33.—Pack complete

stands on the near side of the animal, facing toward the rear; the other, termed the "off" packer, stands on the off side of the animal, facing toward the front. The side packs, being slung on the animal, the "near" packer throws the end of the lash rope over in rear of the animal and the cincha portion under the animal's belly convenient to the "off" packer, who picks up the end of the lash rope and the cincha portion with the left hand and stands erect.

The "near" packer takes hold of the lash rope with the right hand about 5 or 6 feet from the cincha and another hold with the left hand, holding about 2 feet between the hands; he stands close to the animal's neck with both hands extended downward; he draws the right hand backward and, with one motion, swings the rope so when it falls it will lie fore and aft between the side packs, clearing the animal's haunch, and the packer dropping the rope held by the left hand, as shown in figure 35.

With the right hand still holding the rope, he draws a portion between the packs by lowering the right hand by his side, arm's length; then, reaching up, he grips the rope with the left hand; keeping the thumb under the rope, he draws another portion between the packs by lowering the left hand by his side, arm's length.

The packer then swings the hanging portion outward to the right, bringing the left hand, still holding the rope, to the elbow of the right arm; then raises both hands, leaving the loop on the outside of the right arm, as shown in figure 36.

Now, bring the right hand, holding the rope, to the center of the pack and, with both hands, throw the standing rope held in the right hand over the center of the load to the "off" packer, and the running rope between the packs held in the left hand over the animal's neck, allowing the back of the left hand to rest on the animal's neck. With the right hand draw 6 feet or more of the running portion between the packs to form the rear half of the diamond and throw this rope to the rear of the "near" pack, freeing both hands of the rope.

The "near" packer takes hold of the running rope on the mule's neck with the left hand forward of the right and, with the assistance of the "off" packer brings the running rope to the center of the load on the side of the standing rope, at the same time slipping the right hand down the rope to a point about midway between the pack and the "boot"; reaches for this rope by passing the left hand between the standing rope and the aparejo and grips the rope above the right hand; slips both hands down the rope, at the same time parting them from each other for a space of about 10 inches; then, holding the rope in a horizontal position, jams this portion down between the two cinchas under the aparejo, and the hitch is formed on the "near" side ready to tighten. (See fig. 37.)

To make the hitch on the "off" side, the "off" packer, having picked up the end of the rope and cincha, holds them in the left hand with mouth of cincha hook to the front. He looks for the standing rope to be thrown over the center of the load by the "near" packer. As the rope comes over, he grips it as high as his arm can conveniently reach and immediately places the cincha hook about 6 or 8 inches under the aparejo and draws down the slack on the standing rope by one or two quick pulls; then, lowering the cincha hook for convenience, he engages the standing rope on the cincha hook from inside, drawing the rope outward, or from above, drawing downward. This will leave the standing rope next to the aparejo and the running rope on the outside of the hook.

The left hand, holding the end of the rope, is now placed on top of the running rope between the right hand and the cincha hook; both ropes are gripped with the thumb under the running rope; the right hand is allowed to slip upward on the running rope, and, with the assistance of the "near" packer, this rope is brought to the center of the load; the left hand will immediately follow the right hand to the center of the load, which brings both hands together.

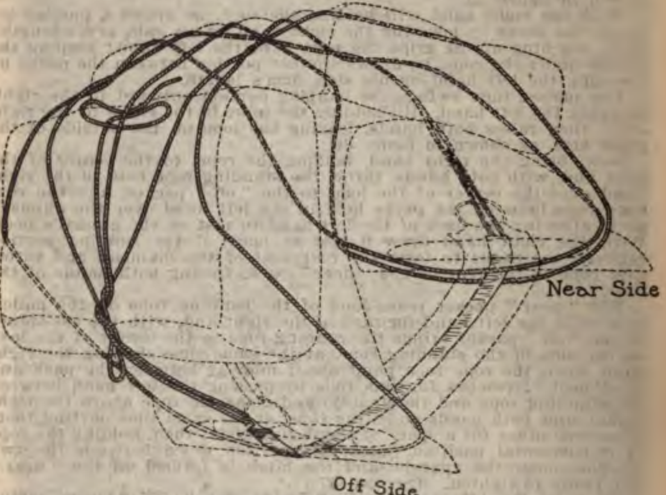


Fig. 34—Diamond hitch

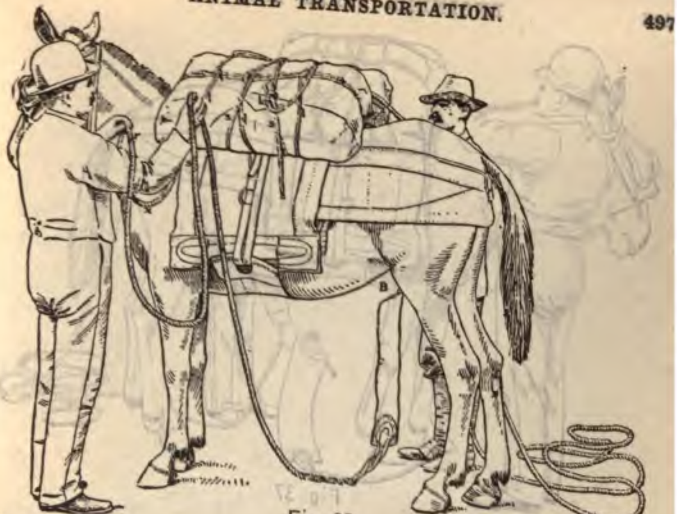


Fig. 35

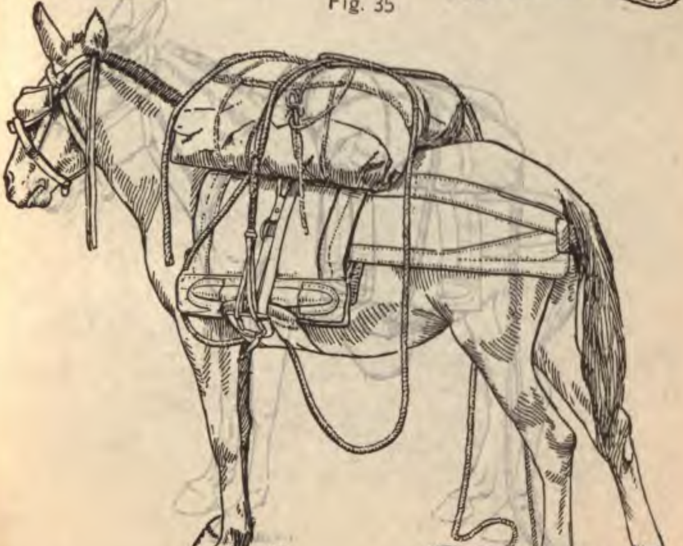


Fig. 36

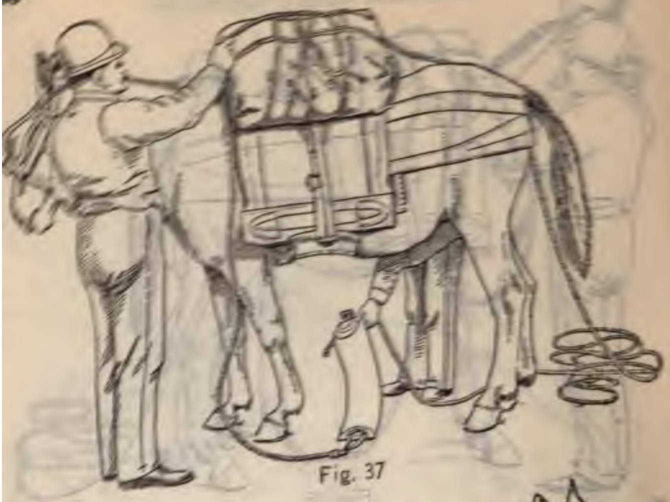


Fig. 37

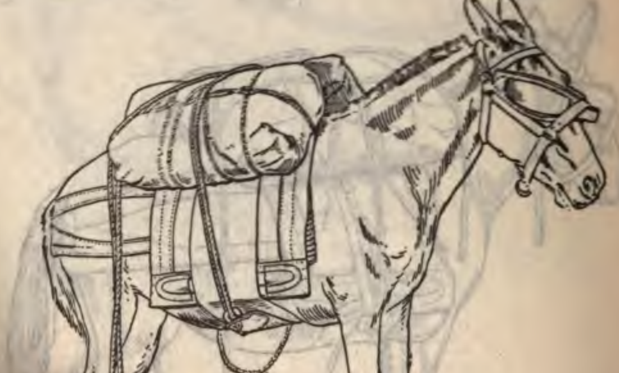


Fig. 38

With the right hand draw the end of the rope forward which is eld by the left hand so that about 12 inches will fall on the "near" de of the animal's neck, and the hitch is formed, ready to tighten, as iown in figure 38.

(*b*) The double hitch. The double hitch is made as described for ie single diamond hitch, with the two following exceptions:

The "near" packer, before passing the running rope to rear of ıck, brings the running rope up, from the animal's neck, and lays it ı the center of the load, in front of the standing rope. He then ıkes sufficient slack on the running rope between the packs and lays : throws it to rear of load, thus causing it to ride over both the running and the standing ropes; he then takes the rope in front of the anding rope and brings it down from right to left between the anding rope and pack and under the boot of the aparejo in the cusımary manner.

The "off" packer, instead of placing the end of rope between the anding and running ropes, places it under both, then raises to center load, and drops about 12 inches of end on "rear" side of animal's eck, and hitch is formed ready to tighten.

The hitch is tightened in the usual manner, as in the operation of ie "diamond."

30. **Pack outfits.**

	Contents of boxes.	
PACK NO. 1, EQUIPMENT.		
ırpenters, farriers, and saddlers:	*Box 1–A.*	*Box 1–B.*
Bag, nail, 10-pound	1	1
Bag, for small articles	1	1
Bar, pinch, small	1	1
Box, pack No. 1	1	1
Brace and bits (7 auger and 1 screw driver), hand saws, C. C. (2) ... set	1	....
Carpenter's bag; framing chisels (3); claw hammers (2); hatchets (4); 50-foot metallic tape; monkey wrench; ship augers, 7/16-inch, handled (2); side-cutting pliers (2); and steel square ... set	....	1
Hammer, sledge, 8-pound	....	1
Farrier's hammer, shoe knife (in case), nippers, pincers, shoeing rasp, 16-inch, and flat bastard file, 12-inch ... set	1	....
Revolving punch, rivet set, and stitching awl ... set	....	1
Rolls, canvas, for tools	1	2
PACK NO. 1, SUPPLIES.		
ırpenter:		
Bolts, drift, ½-inch	20	20
Carpenter pencils (6), chalk, ¼ pound, chalk lines (2) ... set	....	1
Nails, 60-penny (10 pounds), 16-penny (10 pounds), pounds	10	10
ırrier:		
Beeswax (2 ounces), harness needles (2 papers), harness rivets, assorted (1 pound), harness thread (2-ounce ball) ... set	....	1
Nails, horseshoe, pounds	3	....
Shoes, mule, fitted	6	....

	Contents of boxes.	
PACKS NOS. 2 AND 3, EQUIPMENT.	*Boxes 2–A and 3–A each.*	*Boxes 2–B and 3–B each.*
Demolition:		
Canvas bucket; cold chisel; pinch bar, small (of each)	....	1
Clasp knife; crimper; cap box; match box (of each)	1	1
Pick mattock, mining; ship auger, 1¾-inch, handled (of each)	....	1
Pliers, side-cutting	....	2
Shovels, mining; sledge (8 pounds); single-bit drill, small; miner's spoon (of each)	1	....
Roll, canvas, for tools	1	1
PACKS NOS. 2 AND 3, SUPPLIES.		
Demolition:		
Caps, detonating	50	50
Cord, detonating (2 spools), and 12 unions .... set	1	1
Explosive, pounds	45	45
Fuse, Bickford, feet	100	100
Fuse lighters, Bickford	30	30
Lashings, manila, ½-inch, 18 feet	1	1
Matches, safety, boxes	6	6
Twine, hemp, 2-ounce ball	1	1
Wire, copper, No. 30, ¼-pound spool	1	1
PACK NO. 4, EQUIPMENT.		
Pioneer equipment:	*Box 4–A.*	*Box 4–B.*
Axes, handled, 36-inch	3	3
Boxes, pack, No. 4	1	1
Pick mattocks, handled } E. D. pattern, mining	5	5
Shovels } E. D. pattern, mining	10	10
PACK NO. 5, EQUIPMENT.		
Pioneer equpmient:	*Box 5–A.*	*Box 5–B.*
Blocks—6-inch, double; 6-inch, single; 6-inch, snatch. set	3	3
Boxes, pack No. 5	1	1
Hatchets	....	2
Machetes, with sheaths	5	5
Rope, manila, ¾-inch diameter, 200-foot coils	1	1
Saws, folding, with cases	1	1
Saws, crosscut, hand, 20-inch	2	....

PART VII

TABLES OF WEIGHTS, MEASURES, AND SPECIFIC GRAVITIES

T VII—TABLES OF WEIGHTS, MEASURES, AND SPECIFIC GRAVITIES.

WEIGHTS AND MEASURES.

TABLE I.

LINEAR EQUIVALENTS.

.	M.	Kilom.	In.	Ft.	Yd.	Rod.	Chain.	Furlong.	Mile.
1	.01	10^5	.3937	.0328	.01094	.002	.000497	.0000497	.0000062
100	1	.001	39.37	3.281	1.0936	.20	.04971	.00497	.000621
10^5	1000	1	39370	3281	1093.6	200	49.71	4.97	.6214
.54	.0254	.0000254	1	.00083	.0278	.005	.0000126	.00000126	.0000158
.48	.3048	.0003048	12	1	.333	.061	.01515	.001515	.0001654
.44	.9144	.0009144	36	3	1	.182	.04545	.004545	.000568
3.0	5.03	.005	198	16.5	5.5	1	.25	.025	.003125
012	20.12	.02012	792	66	22	4	1	.10	.0125
120	201.2	.2012	7920	660	220	40	10	1	.125
925	1609	1.609	63360	5280	1760	320	80	8	1

TABLE II.

CONVENIENT TABLE OF LENGTHS.

yonet (1910), 20.5 inches.
yonet in scabbard, 21.5 inches.
linary ax handle, 36 inches.
linary hatchet handle, 18 inches.
nd shovel (engineer issue), 3 feet.
nd shovel, long handle, 5 feet.
le, 43 inches.
nteen (1910), 7 inches.
con can (1910), 7 inches.

TABLE III.

MARINER'S MEASURE.

eet=1 fathom.
fathoms = 1 cable length.
cable lengths = 1 mile.
80 feet = 1 statute mile.
85 feet = 1 nautical mile.

TABLE IV.

SURVEYORS' MEASURE.

2 inches = 1 link.
links = 1 rod.
ods = 1 chain.
square chains = 1 acre = 160 square rods.
acres = 1 square mile or section.
square miles = 1 township.

TABLE V.

CIRCULAR MEASURE.

60 seconds = 1 minute.
60 minutes = 1 degree.
30 degrees = 1 sign.
90 degrees=1 quadrant.
4 quadrants = 12 signs = 360 degrees = 1 circle.

TABLE VI.

APPROXIMATE METRIC EQUIVALENTS.

1 decimeter = 4 inches.
1 meter = 1.1 yards.
1 kilometer = ⅝ mile.
1 hectare=2½ acres.
1 stere = 1 cubic meter = ¼ cord.
1 liter = 1.06 quarts liquid = 0.9 quart dry.
1 hectoliter=2⅞ bushels.
1 kilogram = 2⅕ pounds.
1 metric ton = 2,200 pounds.

TABLE VII.

VOLUME AND CAPACITY EQUIVALENTS.

Cubic inches.	Cubic feet.	Cubic yards.	U. S. apothecary liquid ozs.	U. S. quarts.		U. S. gallons.		Bushels U. S.	Liters (1).
				Liquid.	Dry.	Liquid.	Dry.		
1	.0005787	.00002143	.5541	.01732	.01488	.004329	.003720	.0004650	.01639
1728	1	.03704	957.5	29.92	25.71	7.481	6.429	.8036	28.32
46656	27	1	25853	807.9	694.3	202.0	173.6	21.70	764.6
1.805	.001044	.00003868	1	.03125	.02686	.007813	.006714	.0008392	.02957
57.75	.03342	.001238	32	1	.8594	.25	.2148	.02686	.9464
67.20	.03889	.001440	37.24	1.164	1	.2909	.25	.03125	1.101
231	.1337	.004951	128	4	3.437	1	.8594	.1074	3.785
268.8	.1556	.005761	148.9	4.655	4	1.164	1	.125	4.405
2150	1.244	.04609	1192	37.24	32	9.309	8	1	35.24
61.02	.03531	.001308	33.81	1.057	.9081	.2642	.2270	.02838	1

TABLE VIII.

WOOD MEASURE.

108 cubic feet=1 stack of wood.
128 cubic feet=1 cord of wood=4×4×8 feet.

TABLE IX.

SHIPPING MEASURE.

vessel will carry=length of keel × breadth at main
hold in feet÷95 (the cubic feet allowed for a ton).
nnage. For a double-decker instead of the depth
he breadth of the beam.

Register ton: For register tonnage or for measurement of the entire internal capacity of a vessel: 100 cubic feet=1 register ton. This number is arbitrarily assumed to facilitate computation.

Shipping ton, for measurement of cargo:

$$40 \text{ cubic feet} = \begin{cases} 1 \text{ U. S. shipping ton.} \\ 32.143 \text{ U. S. bushels.} \\ 31.16 \text{ imp. bushels.} \end{cases}$$

$$42 \text{ cubic feet} = \begin{cases} 1 \text{ British shipping ton.} \\ 32.719 \text{ imp. bushels.} \\ 33.75 \text{ U. S. bushels.} \end{cases}$$

TABLE X.

MEASURE OF BRICKWORK.

Brickwork is measured by the thousand, and for various thicknesses of wall runs as follows:

8½-inch wall, or 1 brick in thickness, 14 bricks per superficial foot.
12¾-inch wall, or 1½ bricks in thickness, 21 bricks per superficial foot.
17-inch wall, or 2 bricks in thickness, 28 bricks per superficial foot.
21¼-inch wall, or 2½ bricks in thickness, 35 bricks per superficial foot.

An ordinary brick measures about 8¼×4×2 inches, which is equal to 66 cubic inches, or 26.2 bricks per cubic foot. The average weight is 4½ pounds.

TABLE XI.

AREA EQUIVALENTS.

——	Square inches.	Square feet.	Square yards.	Square rods.	Square chains.	Roods.	Acres.	Square miles or sections.
1	1550	10.76	1.196	0.0395	0.002471	0.000984	0.0002471	0.0000003861
0.0006452	1	0.006944	0.0011	0.00002551	0.000001594	0.0000006377	0.0000001594	0.0000000002491
0.09290	144	1	0.1111	0.003673	0.0002296	0.00009184	0.00002296	0.00000003587
0.8361	1296	9	1	0.03306	0.002066	0.0008264	0.0002066	0.0000003228
25.29	39204	272.25	30.25	1	0.0625	0.02500	0.00625	0.000009766
404.7	627264	4356	484	16	1	0.4	0.1	0.0001562
1012	1568160	10890	1210	40	2.5	1	0.25	0.0003906
4047	6272640	43560	4840	160	10	4	1	0.001562
2589998	....	27878400	3097600	102400	6400	2560	640	1

(1 hectare=100 ares=10,000 centiares or square meters.)

TABLE XII.

MASS EQUIVALENTS.

Kilograms.	Grains.	Ounces.		Pounds.		Tons.		
		Troy and apothecary.	Avoirdupois.	Troy and apothecary.	Avoirdupois.	Short.	Long.	Metric.
1	15432	32.15	35.27	2.6792	2.205	0.001102	0.0009842	0.001
0.00006480	1	0.002083	0.002286	0.0001736	0.0001429	0.00000007143	0.00000006378	0.00000006480
0.03110	480	1	1.09714	0.08333	0.06857	0.00003429	0.00003061	0.00003110
0.02835	437.5	0.9115	1	0.07595	0.0625	0.00003125	0.00002790	0.00002835
0.3732	5760	12	13.17	1	0.8229	0.0004114	0.0003673	0.0003732
0.4536	7000	14.58	16	1.215	1	0.0005	0.0004464	0.0004536
907.2	14000000	29167	32000	2431	2000	1	0.8929	0.9072
1016	15680000	32666	35840	2722	2240	1.12	1	1.016
1000	15432356	32151	35274	2679	2205	1.102	0.9842	1

TABLE XIII.

Specific gravities and weights of certain substances.	Average specific gravity water = 1.	Average weight 1 cubic foot.
		Pounds.
Alcohol, commercial	0.833	51.95
Alum	1.72	107.4
Aluminum	2.60	162.0
Ammonia, 60° F	.894	55.81
Asbestos, sheathing paper	1.20	75.0
Ash, American, white, dry	.61	38.0
Ashes, solidly packed	.70	40- 45
Asphalt	1.60	100.0
Ballast, brick, gravel	1.79	111.6
Barley		38.5
Bran		16.7
Brass, sheet	8.24	513.6
Bricks, common	1.922	120.0
Bronze, ordinary	8.40	524.0
Cedar, red and white, dry	.45	28.1
Cement, natural, loose	1.04	65.0
Cement, Portland, loose	1.35	84.2
Cement, natural, solid	2.95	183.9
Cement, Portland, solid	3.15	196.6
Chalk	2.35	146.5
Charcoal		15- 30
Clay, dry, in lump, loose	1.01	63.0
Coal, anthracite, broken of any size, loose		52- 56
Coal, bituminous, broken of any size, loose		47- 52
Coke, loose, good quality		23- 32
Corn, average		44.2
Copper, average	8.82	550.0
Cork	.25	15.6
Earth, common loam, dry		72-100
Earth, common loam, moist		70-100
Earth, common loam, soft mud		104-120
Fir, Douglas	.51	31.8
Gasoline	.72	45.0
Glass, common	2.52	157.0
Gravel, dry	1.79	112.0
Gravel, wet	2.00	125.0
Gypsum, calcined, in lump	1.80	112.0
Gypsum, powder, loose	.97	60.5
Hay, baled		12.5
Hay, loose		4.67
Hickory, average	.85	53.0
Ice, average	.89	56.0
Iron, cast	7.2	448.9
Iron, wrought	7.7	480.0
Lead, commercial, cast	11.36	708.0
ose		53.0
ry	.71	44.3
ne	1.65	103.0
nent	1.68	105.0
		30.8
average	.93	58.2
	.878	54.8
	1.15	71.7
	8.94	557.5

TABLE XIII—Continued.

Specific gravities and weights of certain substances.	Average specific gravity water=1.	Average weight 1 cubic foot.
		Pounds.
Resin	1.09	68.0
Rock, general, 2.2–2.8	2.5	156.25
Salt, coarse		45–70
Sand, dry		90–106
Sand, wet		118–129
Snow, fresh fallen		5–12
Snow, moistened and compacted		15–50
Stone, general, 2.2–2.8	2.5	156.25
Steel, cast	7.9	492.6
Steel, wrought	7.85	489.6
Sugar	1.60	100.0
Tar	1.00	62.5
Tin, rolled	7.40	461.5
Tin, cast	7.30	455.0
Turf		20–30
Vinegar	1.08	67.5
Water, pure, at 60° F., bar. 30″	1.00	62.355
Water, sea	1.028	64.1

NOTE.—The word "dry" in connection with wood indicates the presence of not more than 15 per cent moisture. Green timbers will weigh from one-fifth to one-half more than dry—ordinary building timbers, tolerably seasoned, one-sixth more.

Authorities for the above: Trautwine, Kidder, and Tables of Organization, United States Army.

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